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# More Active for Greater Customer Satisfaction

## 2 極化するクルマのニーズへ応えるトランスミッション技術開発の必要性

Necessity of developing transmission technologies  
to meet bipolarizing vehicle needs

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自動運転がカーメーカー各社の技術開発により現実味を帯びてきている一方、2015年の日本カーオブザイヤーを受賞したスポーツカーモデルのようにまったく別の方向性を目指すクルマも脚光を浴びており、クルマの多様化はますます進みつつある。このように一見相反する技術開発が進むのは、クルマが人にとって生活を共にする良きパートナーであるからに他ならない。クルマは単に効率的な移動手段として利用されるだけでなく、移動時間と空間を楽しむ、あるいは運転そのものを楽しむ手段として、お客さまにとって重要な役割を担っている。そのようなお客さまの要求の多様化に合わせてクルマが進化するよう、トランスミッションもクルマとともに進化しなければならない。

環境性能はクルマの重要な要求性能の一つであり、各国のCO<sub>2</sub>排出削減の規制は、2025年に向かって年々厳しさを増している。先に行われたCOP21においても世界共通課題として地球温暖化対策の必要性が再認識され、今後は先進国のみならず、新興国においてもほぼ同じペースで規制強化が進むであろう。従って各社は最新のCO<sub>2</sub>排出低減技術を、世界中どの地域においてもほぼ同時に採用することが必要になると考えられる。その要求に応えるために、例えば、コンベンショナルなパワートレインとして、エンジンのダウンサイジング技術が進化し、これに伴い制振性能を高めたダンパー等のトランスミッション技術も急速に進化している。また、特にモータリゼーションの急速な発展を遂げているPost BRICsも含めた新興国では、より過酷な使われ方を考慮した対応が必要になってくるであろう。

さらに、日本をはじめとする先進国市場で顕著なドライバーの高齢化問題や、新興国におけるエントリーユー

Autonomous driving is beginning to seem more real owing to the R&D efforts being made by the automakers. Meanwhile, other vehicles aimed in a completely different direction are also in the limelight, such as the sports car model that won the 2015 Japan Car of the Year award. Vehicles are increasingly becoming much more diverse. The reason why technological developments appear to be proceeding in these contradictory directions is simply that vehicles are an excellent partner for people in their everyday lives. Vehicles are not used only as an efficient means of transportation. They also fulfill an important role for customers as a means of enjoying time and space while traveling or as means of enjoying the act of driving. As vehicles evolve to meet this diversification of customers' needs and wants, transmissions have to also evolve together with vehicles.

Environmental friendliness is one of the critical attributes required of vehicles. Regulations on CO<sub>2</sub> emissions are becoming increasingly tighter every year in countries around the world toward the year 2025. At the 2015 United Nations Climate Change Conference (COP 21) held near the end of last year, the necessity of adopting measures for restraining global warming was reaffirmed as a shared global issue. Presumably, not only the developed countries but also emerging countries will tighten their environmental regulations at nearly the same pace in the coming years. Accordingly, companies will probably need to deploy their latest CO<sub>2</sub> emission reduction technologies in all regions of the world at nearly the same time. In order to meet the stricter requirements, for example, technologies are evolving for downsizing the engine in conventional powertrain systems. In this connection, transmission technologies are also rapidly evolving such as dampers and other devices with improved vibration damping performance. Measures to cope with harsher driving usage must also be devised for emerging countries, including post-BRICs in particular where motorization is advancing rapidly. Moreover, the attributes of drivers themselves are also changing along with a broadening of their driving styles and preferences. These trends include the issue of the

ザーの増加など、ドライバー自身の属性の変化とともに運転スタイルや趣向も拡大しつつある。

このような要求の多様性を考慮してゆくと、トランスミッションへの要求性能についても先に述べたように次の2つの方向に分けられると考えられる。ひとつは、効率的かつ快適な移動手段としてのいわばRationalな方向（人の情感に左右されない合理的な方向）であり、燃費、快適性、安全などはこのための重要な要求性能である。そしてもうひとつは、運転そのものを楽しむ、ドライビングプレジャーを享受する手段としてのEmotionalな方向（人の情感を重視する方向）であり、ダイレクト感やスポーティさといったいわゆる人馬一体の感覚が重要な要求性能となる。

環境対応技術の進化の典型的な例は電動化であり、ハイブリッド車が年々増加している。CVTが特に日本を中心に普及拡大が続いているのも、環境性能の高さが大きな理由であることは疑いの余地がない。しかし、ハイブリッド車においてもCVTにおいても燃費がよいというだけでなく、お客さまにとってのさらなる付加価値向上技術として、ドライバーの情感にマッチする価値を提案していくことが必要となってきている。たとえば、ドライビングプレジャーのための技術進化として、アダプティブシフトのようなドライバーの加速意図を検知することによる最適変速制御が既に多用されており、ナビゲーションシステムとの協調によってさらに最適に山岳路やワインディングロードでの運転を楽しむことが可能となっている。

変速自由度の高いCVTはドライバーの要求にきめ細かく対応することができるためこうした制御技術への対応がしやすく、燃費向上などの効率化に貢献するRationalな性能と運転の楽しさを演出するEmotionalな性能の両方を実現する技術として期待されており、今後ますますの進化が望まれる。

クルマがこれからも人の生活の良きパートナーであり続けるためには、社会環境とドライバーの要求の両方に対応することが不可欠である。環境性能とドライビングプレジャーの両立、それを磨き上げ、極めることが今後ますます重要であり、それはトランスミッション業界がクルマ社会に貢献しつづけるための使命である。ジャトコはこれからも人と社会の要求に常に真摯に耳を傾けつつ、絶え間ない技術開発を続けクルマ社会の未来に貢献していく。

pronounced increase in the number of aged drivers in developed markets like Japan and the growing number of entry-level drivers in emerging economies.

When one considers this diversification of requirements, the performance demanded of transmissions can also presumably be divided into two directions like in the example mentioned above. One might be termed a “rational” direction that pursues an efficient and comfortable means of transportation unaffected by human emotion. Fuel economy, comfort, safety and other aspects are important performance requirements in this regard. The other is an “emotional” direction that pursues a means for enjoying driving pleasure in the very operation of a vehicle. This direction emphasizes human emotion. A directly connected feel, sportiness and a feeling of unity between the car and driver are important performance requirements in this regard.

Electrification is a typical example of the evolution of environmental technology, and the number of hybrid vehicles on the road is increasing every year. There is no doubt at all that one of the major reasons why CVTs have continued to spread widely especially in Japan is their outstanding environmental performance. However, for both hybrid vehicles and CVTs, it has become necessary to propose value matching drivers’ emotion as a way of further enhancing added value for customers, instead of just providing good fuel economy. For example, one technological advance for enhancing driving pleasure is optimal shift control, which has already been widely adopted in our transmissions to detect the driver’s intention to accelerate, as exemplified by Adaptive Shift Control. Through collaborative operation with the car navigation system, this shift control technology further enables drivers to enjoy optimal driving pleasure on mountainous or winding roads.

Such control technology can easily be embodied in CVTs with their high level of shift flexibility to enable a fine-tuned response to drivers’ demands. Much is expected of CVTs as a technology for delivering both rational performance contributing to greater efficiency such as improved fuel economy and also emotional performance for providing driving pleasure. In this respect, the further evolution of CVTs in the years ahead is strongly desired.

If vehicles are to continue to be an excellent partner for people in everyday life, it is indispensable to meet the demands of both the social environment and drivers. That means providing both environmental performance and driving pleasure. It will be increasingly important in the coming years to further refine and optimize our ability to accomplish that. That is the mission of the transmission industry in order to continue to contribute to motorized society. At JATCO, we will continue to listen intently to the needs of both people and society at all times as we proceed with our ceaseless efforts to develop technologies for contributing to the motorized society of the future.



# Jatco CVT7 W/R企画の狙い

Aims of the Jatco CVT7 W/R Project

副社長

Executive Vice President

永倉 均

Hitoshi NAGAKURA

**抄 録** 弊社は2015年08月より、コンパクトセグメント車向けJatco CVT7 W/R(以降「CVT7 W/R」とする)の生産を加特可(広州)自動変速機有限公司(中国広東省広州市:以下JGZとする)にて開始した。本稿では、CVT7 W/Rの企画・開発に至った背景について、2009年に発売したJatco CVT7の市場反響、コンパクトセグメント車の2ペダル化動向、政府の環境規制などの観点から紹介する。

**Summary** In August 2015, JATCO launched production of the Jatco CVT7 W/R for use on compact segment vehicles at JATCO Guangzhou Automatic Transmission Ltd. (JGZ) located in the city of Guangzhou in Guangdong province in China. This article describes the background behind the planning and development of the CVT7 W/R, focusing on the market response to the Jatco CVT7 released in 2009, the trend toward 2-pedal vehicles in the compact segment, and the Chinese government's environmental regulations, among other aspects.

## 1. はじめに

## 1. Introduction

弊社は2009年7月に小型化・軽量化・燃費性能向上をうたった副変速機付小型CVT, Jatco CVT7(以降「CVT7」とする)の生産を開始し、軽自動車からコンパクトセグメントまでのFWD小型車全域をカバーしている。2015年9月現在のグローバル累計生産台数は834万台に達し、FWD車160Nm以下のトルク帯におけるトランスミッションのグローバルシェア8%を占めるに至っている(当社調べ)。CVT7は日本軽自動車および、日本・欧州・北米のA/B/Cセグメント車をメインターゲットに想定して企画開発したが、発売後は中国、ASEAN、および中南米のマーケット拡大と共に販売台数を伸ばしてきた。グローバルにCVT7のマーケットと台数が増えていくとともに、CVT7だけでカバーしきれない新たなニーズが生まれてきており、性能向上を取り入れたユニット企画が必要と考えCVT7 W/Rを開発した。

In July 2009, JATCO began producing the smaller, lighter Jatco CVT7 featuring an auxiliary gearbox and providing improved fuel economy. This small-capacity CVT is suitable for application to the entire spectrum of front-wheel-drive (FWD) small vehicles, ranging from minivehicles to the compact segment. The cumulative global production volume of the CVT7 reached 8.34 million units in September 2015. Based on in-house research, it has an 8% share of the global transmission market for FWD vehicles having a torque capacity of up to 160 Nm. The main targets envisioned for the CVT7 in the planning and development stages were minivehicles in Japan and A-, B-, and C-segment vehicles in Japan, Europe and North America. Following its release, however, the sales volume grew along with the expansion of the vehicle markets in China, ASEAN countries and Central and South America. As the markets and sales volume of the CVT7 continued to expand globally, new customer needs emerged that could not be met by the CVT7 alone. Accordingly, it was concluded that a new CVT embodying various performance improvements should be planned, which led to the development of the CVT7 W/R.

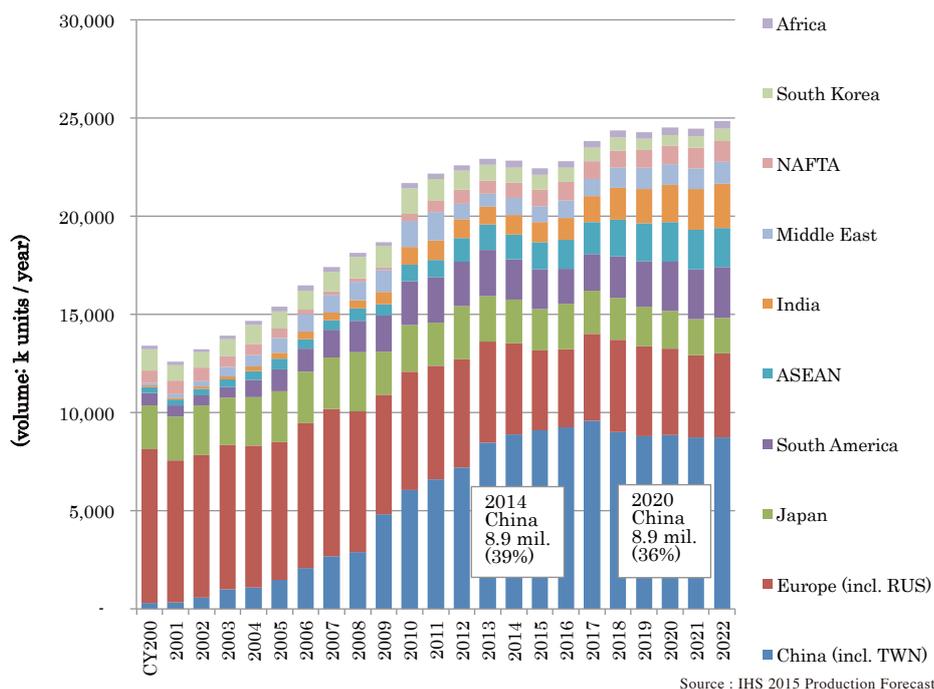


Fig. 1 Sales volume of 100-160 Nm FWD vehicles by region

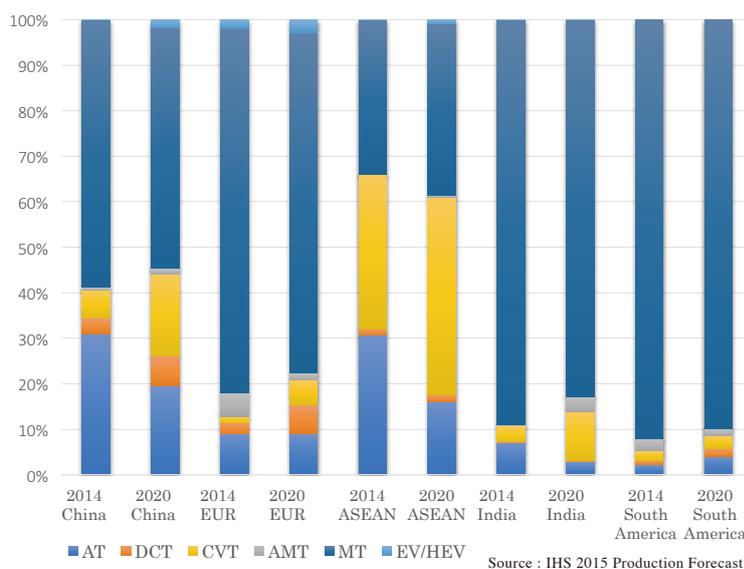


Fig. 2 Transmission mix of 100-160 Nm FWD vehicles by region

## 2. コンパクトセグメントのFWD 2ペダル車の市場動向

コンパクトセグメントのトルク帯である最大エンジントルクが 100-160NmクラスのFWD車の市場規模は、現在年間22.8百万台であり、FWD車全体の36%を占める。リージョン別の台数規模が大きい中国マーケット(Fig.1)では、2ペダル化が進んでおり、2ペダル車の中でのシェアはステップAT車がトップであり、CVT車が続けているが、2020年に向けてCVT車シェアが増加する予測である(Fig.2)。

## 2. Market Trends for 2-pedal FWD Vehicles in the Compact Segment

The size of the global market for FWD vehicles having a maximum engine torque range in the 100-160 Nm class in the compact segment is currently around 22.8 million units annually, accounting for 36% of all FWD vehicles. Two-pedal vehicles are increasing in the Chinese market, which has the largest sales volume in this vehicle torque class by region (Fig. 1). Vehicles fitted with a stepped automatic transmission

また、中国マーケット以外においても、グローバル規模で(1)環境規制対応(2)運転性向上への期待といったお客さまニーズが変化しており、ニーズに合わせた商品をCVT7 W/Rの企画に反映させていくことを考えた。中国での環境規制強化の動きとマーケット規模拡大に合わせて、CVT7 W/Rの展開を中国マーケットよりスタートすることとした。

### 3. 中国マーケットにて求められる2ペダル車向け トランスミッション

現在中国マーケットは最大の成長市場であり、欧米・韓国・日系合弁OEMを中心にMT車から2ペダル車への移行が進んでいる。

深刻化する大気汚染対策として、環境規制強化の政府方針が打ち出され、2020年CO<sub>2</sub>排出量は117g/kmをターゲットとする厳しい規制対応が、どのOEMにとっても急務である(Fig.3)。CVT7のパートレイン効率をさらに改善し、車両燃費向上に貢献するCVTの企画が必要であった。

CVTユーザーの評価を分析すると、CVTの燃費性能と共に「スムーズさ」は高く評価されている。しかし、ドライバーのアクセル操作からの応答性・追従性の点において、他のトランスミッションと差があることは否めず、運転する楽しさ、わくわく感をより多く感じていただくために、レスポンス性能改善を「ダイレクト感」の向上としてCVT7 W/Rで取り組むことにした(Fig.4)。

account for the largest market share among 2-pedal vehicles in China, followed by CVT-equipped vehicles (Fig. 2). It is projected, however, that the share of CVT-equipped vehicles will increase further towards 2020. Apart from the Chinese market, customer needs are changing elsewhere on a global scale with respect to (1) compliance with environmental regulations and (2) expectations for improved driveability. It was felt that product attributes meeting those needs should be reflected in the planning of the CVT7 W/R. In view of the trend toward tighter environmental regulations and the expanding scale of the vehicle market in China, it was decided to deploy the CVT7 W/R first in the Chinese market.

### 3. Transmissions demanded for 2-pedal Vehicles in the Chinese Market

The Chinese market is currently the largest growth market for vehicles worldwide. A transition is under way from manual transmission vehicles to 2-pedal vehicles among vehicle manufacturers in joint ventures with European, American, Korean and Japanese automakers.

The Chinese government has adopted a policy of tightening environmental regulations as a measure for curbing worsening air pollution. Every vehicle manufacturer is now facing the urgent task of complying with a tough CO<sub>2</sub> emissions regulation that sets a target of 117 g/km in 2020 (Fig. 3). Therefore, it was necessary to plan a CVT capable of contributing to improving vehicle fuel economy through further improvement of the powertrain efficiency of the CVT7.

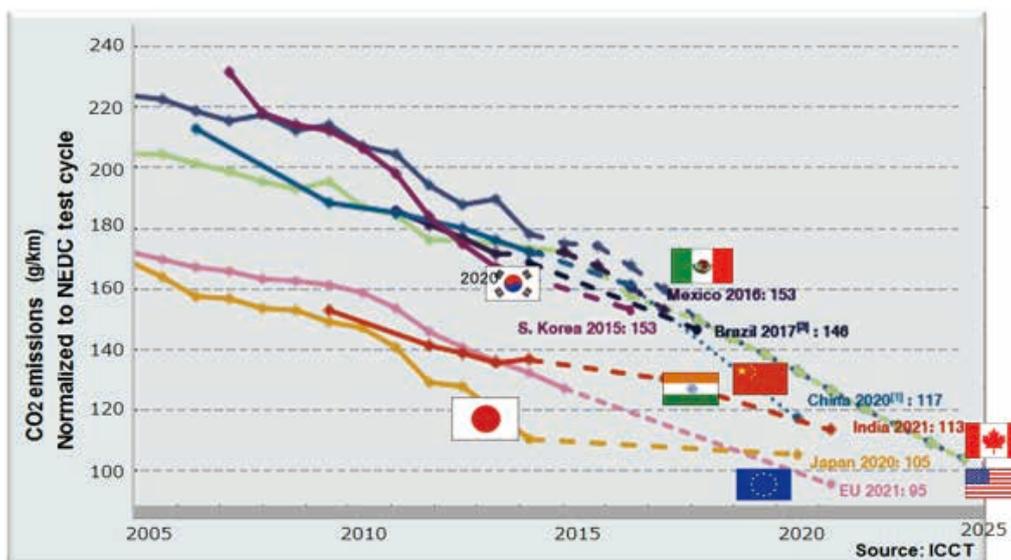


Fig. 3 CO<sub>2</sub> emissions trend(NEDC)

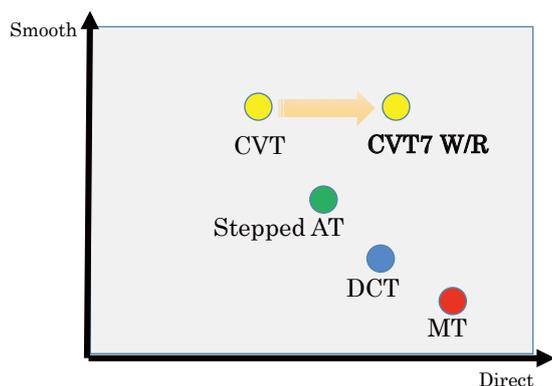


Fig. 4 Direct feeling improvement target

さらに、CVT7が搭載されている車両プラットフォームに引き続き搭載できるパッケージングであることが前提であり、燃費改善の方策において大幅なサイズアップは行わない手段を検討する必要があった。

#### 4. CVT7 W/Rの商品コンセプト

前項にて記したマーケットが求める2ペダル車向けトランスミッションへの期待の変化に応えるため、CVT7をアップデートし、磨き込んだ旗艦モデルとして、CVT7 W/Rの企画へまとめた。

- ・燃費性能の3%向上(レシオカバレッジ20%拡大、フリクション値低減) (Fig.5)
- ・「ダイレクト感」の向上(新制御)
- ・コンパクトセグメント車に搭載できるパッケージングの確保

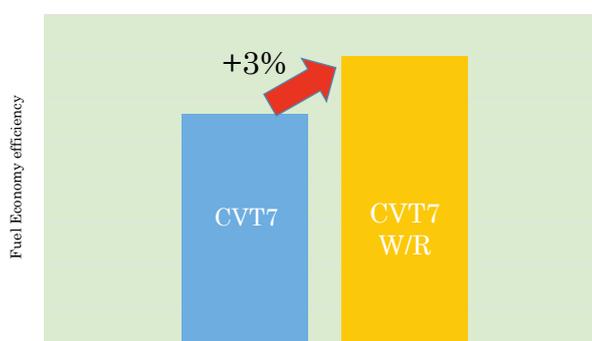


Fig. 5 Fuel economy improvement target

An analysis of evaluations by CVT users showed that along with the excellent fuel economy obtained with CVTs, smoothness was also highly rated. However, it is undeniable that a gap exists with other types of transmissions in terms of the CVT's ability to respond to and track the driver's operation of the accelerator pedal. In order to enable drivers to feel greater driving pleasure and excitement, it was decided to focus efforts on improving responsiveness as a means of enhancing the direct feel of power delivery provided by the CVT7 W/R (Fig. 4).

In addition, the new CVT was premised on the assumption that the packaging would continue to be mountable on the vehicle platforms to which the CVT7 is fitted. This meant that methods had to be studied for avoiding any appreciable increase in size due to the measures to be adopted for improving fuel economy.

#### 4. Product Concept of the CVT7 W/R

In order to respond to the aforementioned changes in expectations for the type of transmission demanded by the market for 2-pedal vehicles, measures for updating the CVT7 were refined into a flagship model that was incorporated into the planning of the following product concept of the CVT7 W/R.

- 3% improvement in fuel economy by expanding ratio coverage by 20% and reducing friction (Fig. 5)
- Improvement of direct feel by adopting new control procedures
- Assurance of packaging mountable on compact segment vehicles

5. おわりに

既存のCVT7だけでカバーしきれない新たなニーズに応える新ユニットとして、CVT7 W/Rを企画した。高い燃費性能を実現するためのレシオカバレッジの20%拡大、およびフリクション低減のための新技術の採用、ドライバーの感性に合う「ダイレクト感」を向上するための新制御、搭載性を維持するためのパッケージングの確保等を企画に盛り込み、新たなニーズに応え得るユニットとしてマーケットに投入することができた(Fig.6)。本誌においてCVT7 W/Rを特集することができるまでに至り、感無量である。CVT7 W/R特集の本冒頭記事の紙面をお借りして、数々の課題を乗り越えて本企画を成功裏に導いていただいた、関係各諸氏、社内外の多くの方々に深く感謝の意を表す。

5. Conclusion

The CVT7 W/R was planned as a new unit capable of responding to new needs that could not be met by the existing CVT7 alone. Higher fuel economy was achieved by expanding the ratio coverage by 20% and adopting new technologies for reducing friction. New control procedures were applied to improve the direct feel of power delivery matching drivers' sensibilities. Steps were taken to assure packaging that would maintain excellent mountability. These and other measures were incorporated into the planning of the CVT7 W/R to achieve a unit that was successfully launched to meet new market needs. That we have now reached the point of publishing this special feature focusing on the CVT7 W/R in the JATCO Technical Review fills me with deep emotion. In this opening article of the special feature on the CVT7 W/R, I would like to take this opportunity to profoundly thank the many people involved both inside and outside the company for their invaluable cooperation in overcoming numerous issues that led to the successful completion of this project.

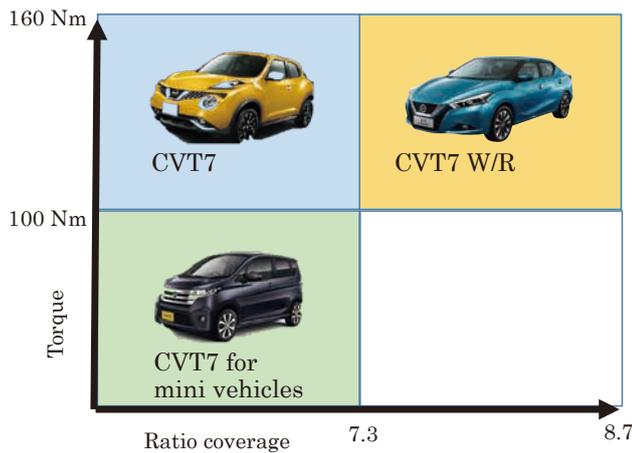


Fig. 6 Product concept of the CVT7 W/R



# Jatco CVT7 W/Rの概要

Overview of the Jatco CVT7 W/R

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**抄 録** 2009年より生産を開始した世界初の副変速機付CVTであるJatco CVT7(以下 CVT7)は、この6年で900万台を超えるCVTとなった。生産当初は日本を中心としたマーケットに展開をした後、中国、北米他グローバルへの展開をしてきた。特に小型車向けについては、グローバル展開がメインとなり、各地域ごとにお客さまの要望に応える必要が出てきた。ここについては、日本、北米のようなステップATからの乗り換えではなく、MTをメインとした市場への対応もあり、その運転性に関する要求が従来と異なっている。また中国においては燃費規制への対応やお客さまの関心が高くなっている地域となっている。そのため、CVT7に対してよりワイドな変速比幅を必要とするお客さま向けにJatco CVT7 W/R(以下CVT7 W/R, Fig.1)を開発した。

**Summary** Over nine million units of the Jatco CVT7 which is the world first CVT with an auxiliary gearbox have been produced in the six years since it went into production in 2009. Initially, the CVT7 was mainly marketed in Japan, and subsequently it was also deployed in China, North America and other global markets. Global marketing has mainly targeted application to small vehicles in particular. It has become necessary in recent years to respond to customer requirements in each geographical region individually. This involves satisfying not only customers switching from a stepped automatic transmission such as in Japan and North America, but also those in markets where manual transmissions are the mainstream. Requirements concerning driveability now differ from what they were before. There is also a need to comply with tighter fuel economy standards in China and the heightened interests of customers in other regions. Therefore, the Jatco CVT7 W/R (Fig. 1) was developed for customers who require wider ratio coverage than that of the CVT7.

## 1. はじめに

世界の自動車登録台数推移から、今後、自動車登録台数は拡大の一途をたどることは間違いない。全体に対する小型車の比率は約3割、台数規模でいうと約2400万台と高く、重要な市場である。この小型車領域をトランスミッションの視点で見た時に、2ペダルの比率は2015年現在35%であるが、今後2021年には40%まで拡大する可能性を持っている。また、世界の国々での燃費向上(燃費規制)の要求は高く、小型車も対応が必要とされている。一方で、グローバルな市場に対応するためには、多様な環境や、お客さまの使い方により、燃費向上だけでなく、運転性の向上も同時に求められている。

CVTは無段階でエンジン回転をコントロールすることができ、エンジンの燃焼効率の良い領域を使うことができる。

## 1. Introduction

The recent trend in global vehicle registrations clearly indicates that the number of vehicles being registered will undoubtedly continue to increase in the coming years. Small vehicles account for approximately 30% of the total registrations and represent an important market segment with a high volume of about 24 million units. An examination of the small vehicle segment in terms of the types of transmissions used reveals that two-pedal gearboxes accounted for 35% of the total in 2015. Their share could possibly expand to as much as 40% by the year 2021. There are strong demands in countries around the world for improved fuel economy, and small vehicles are seen as being necessary for complying with tighter fuel economy regulations. Meanwhile, in addition to fuel economy, there are also demands for improved driveability so as to respond

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Fig. 1 Jatco CVT7 W/R

また、発進や変速のスムーズさの点で、他のトランスミッションより有利である。ただし発進時や加速時のダイレクト感においては、まだ他のトランスミッションと差があることを認めざるを得なかった。

今回、副変速機付小型CVTであるCVT7をベースに、このダイレクト感に着目し、新デバイス、新制御を織り込むことで運転性向上を実現した。また、高まる燃費要求に答えるべく、いくつかのデバイスを採用することで、燃費性能もさらに進化させることに成功した。各性能向上によるパッケージングへの影響は最小限とし、小型で競争力のあるパッケージングをキープすることも実現している。

加えて、今回のCVT7 W/Rは、生産開始時のユニット納入先が中国OEMであったため、ジヤトコとして初となる新型マザー級ユニットの海外拠点における生産立上げにチャレンジし、現地化率もさらに向上させることで、為替影響を少なく、また物流時間の短縮もできる競争力を持つことができた。

## 2. CVT7 W/Rの概要

### 2.1. 開発コンセプト

副変速機付小型CVTをベースに、多様な市場に求められる小型CVTを開発すべく、以下をコンセプトとした

- 1) ドライバビリティの向上
- 2) 燃費性能の向上
- 3) 小型車に搭載できるパッケージングの確保
- 4) マザー級ユニットで初となる海外拠点での生産立上げ

to global market needs, including more diversified driving environments and ways in which customers use their vehicles.

A CVT enables seamless control of the engine speed and allows the engine to operate in the region of its best combustion efficiency. CVTs also have an advantage over other types of transmission in terms of providing smooth start-off acceleration and shifting. However, it was previously necessary to admit that CVTs still had a gap with other types of transmissions with respect to a direct feel of power delivery when starting off or accelerating.

The Jatco CVT7 W/R described here incorporates various new devices and new shift control procedures to deliver improved driveability, focusing especially on this direct feel. Developed around the CVT7 which is an existing small-capacity CVT with an auxiliary gearbox, this new CVT also adopts several devices specifically for meeting rising demands for better fuel economy and its performance in this regard was also successfully further enhanced. The impact of each of these performance improvements on packaging was kept to a minimum, thereby retaining the compact, highly competitive package of the base model.

Moreover, at the time production of the CVT7 W/R was launched, the first units were delivered to a Chinese vehicle manufacturer. This meant that JATCO faced the first-ever challenge of launching production of a new mother-class unit initially at an overseas assembly plant. In this regard, by further increasing the percentage of parts procured locally, we reduced the effects of exchange rate swings and also shortened the parts delivery time to give the new unit a high level of competitiveness.

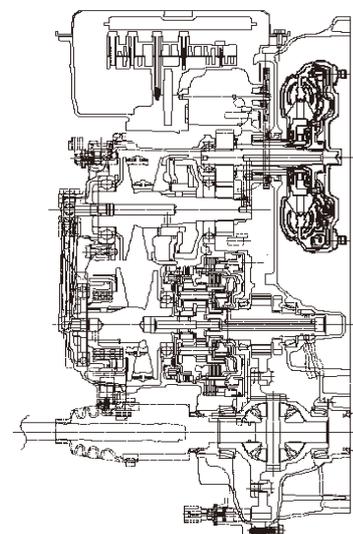


Fig. 2 Cross section

Table 1 Specification

Item	CVT7	CVT7 W/R		
Torque capacity	150 Nm	←		
Gear ratio	Ratio coverage	7.3	8.7	
	Pulley ratio	2.200~0.550	2.200~0.458	
	Final gear ratio	3.753	3.673	
	Planetary gear ratio (Sub transmission)	1st	1.821	←
		2nd	1.000	←
Rev		1.714	←	
Distance between Pulley axes	147 mm	←		
Distance between 1st and 4th axes	183 mm	←		

## 2.2. 主断面&スペック

上記コンセプトで開発を進めてきたCVT7 W/Rは、以下のスペックで各性能を実現している。CVT7のレイアウトを踏襲し(Fig.2)，各軸間はCVT7から変更せず，競争力のあるパッケージングを保ちながらレシオカバレッジを7.3から8.7へ拡大した(Table 1)。

## 3. コンセプト実現に向け採用した技術

このコンセプトの実現に貢献したアイテムを以下に紹介する。

### 3.1. ドライバビリティの向上

#### 3.1.1. CVT搭載車のドライバビリティ

トランスミッションが影響するドライバビリティについて達成すべき指標は、「ダイレクト感」と「スムーズ感」の両立であると本開発において定義した(Fig.3)。CVTは発進時や、変速時のスムーズさに長けているが、ダイレクト感が不足していた。一方でMTは発進時や、変速時にギクシャクするが、ダイレクト感が高いと言える。つまりCVTは「ダイレクト感」を向上させることによって、ドライバビリティを向上させることができると考えた。

CVT7 W/Rの開発では「ダイレクト感」をLinearity, Quick response, そしてConnected feelingの3つの指標で定義した。

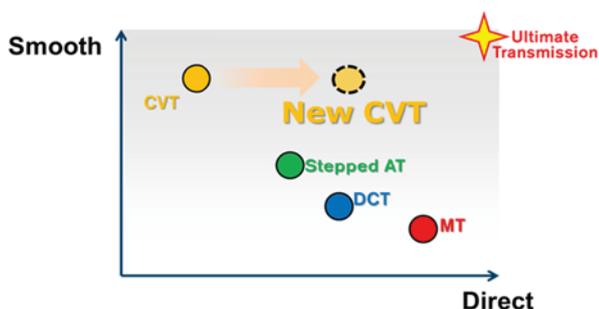


Fig. 3 Positioning of transmissions in terms of smoothness and direct feel

## 2. Overview of the CVT7 W/R

### 2.1 Development concept

The CVT7 W/R was developed based on an existing small-capacity CVT with an auxiliary gearbox and in line with the following concept so as to achieve a compact unit capable of responding to diverse market requirements.

- (1) To improve driveability
- (2) To enhance fuel economy
- (3) To maintain a compact package mountable on small vehicles
- (4) To launch initial production of a mother-class unit for the first time at an overseas assembly plant

### 2.2 Main cross section and specifications

The CVT7 W/R that was developed according to the concept outlined above has the specifications shown in Table 1 to achieve the desired performance attributes. It inherits the layout of the base CVT7 (Fig. 2) and keeps the same distances between the shafts as the latter unit so as to maintain competitive packaging, yet the ratio coverage has been expanded from 7.3 to 8.7.

## 3. Technical Measures Adopted to Achieve the Product Concept

This section explains the technical measures contributing to the attainment of the product concept.

### 3.1 Improvement of driveability

#### 3.1.1 Driveability of a CVT-equipped vehicle

In terms of the effect of the transmission on driveability, two indices were defined that were both to be achieved in developing the CVT7 W/R, namely, direct feel and smoothness (Fig. 3). A CVT provides superior smoothness when starting off and shifting, but has previously lacked a satisfying direct feel of power delivery. In contrast, a manual transmission (MT) suffers from jerkiness when starting off and shifting but provides a better direct feel. In short, it was reasoned that improving the direct feel of the new CVT would have the effect of enhancing driveability.

In developing the CVT7 W/R, the desired direct feel was defined in terms of three indices: linearity, quick response and connected feel. New devices and new shift control procedures were incorporated in the CVT7 W/R to enhance linearity and the connected feel with the aim of improving its direct feel (Fig. 4).

その中のLinearity とConnected feelingについて、新デバイスや新制御を織り込むことで「ダイレクト感」の向上を目指した(Fig.4).

### 3.1.2. Linearityの向上

Linearityは横軸にアクセル開度、縦軸にGピークをとって、アクセル開度とGピークが右肩上がりの理想線形近似線になることを目標とおき、その線からの乖離を指標とした。その指標でCVT7 W/RとCVT7を比較したグラフをFig.5に示す。CVT7 W/Rの方が、近似線からの乖離が抑えられていることを示しており、CVT7 W/Rの方がよりLinearityが高いことが分かる。

この性能を実現するために、発進スリップコントロールという制御を採用した(Fig.6)。これは特に低开度発進時のエンジン回転の過度の上昇、過度のGの発生を抑えて、リニアリティ向上に貢献している。発進スリップコントロール採用にあたっては、ロックアップ(以下L/U)領域が広くなりL/U使用頻度が高くなるため、L/Uフェーシングの耐久性向上が必要となり、新L/Uフェーシングも採用した。

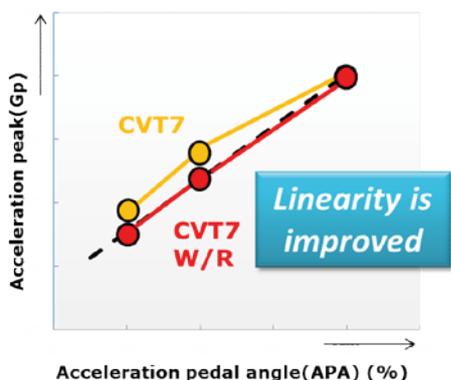


Fig. 5 Linearity of acceleration relative to APA

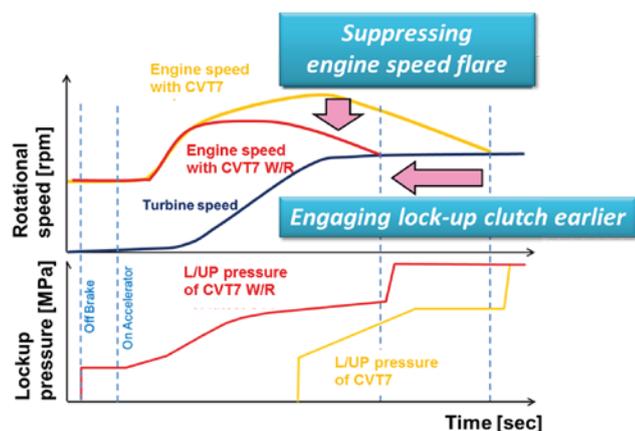


Fig. 6 Lockup operation with start-off slip control

## Direct feeling

- 1. **Linearity relative to accelerator pedal angle**  
Deviation of G peak from straight line relative to APA
- 2. **Quick response**  
Time to G peak or target G [sec]
- 3. **Connected feel**  
Engine speed increase [rpm/sec]

Fig. 4 Three elements defining direct feel and evaluation indices

### 3.1.2 Improvement of linearity

The target set for linearity was to obtain an ideal approximate straight line such that the acceleration (G) peak continuously rises as a function of the accelerator pedal angle when the latter is plotted on the horizontal axis and the acceleration peak on the vertical axis. The deviation from that line was defined as the index of linearity. The graph in Fig. 5 compares the CVT7 W/R and the CVT7 in terms of this index. It is seen that the deviation of the CVT7 W/R from this approximate line is suppressed, indicating that it provides better linearity than the previous unit.

Start-off slip control was adopted for the CVT7 W/R to achieve this improved linearity (Fig. 6). This control contributes to improving linearity by inhibiting an excessive rise in engine speed and the generation of excessive G, especially when starting off under a condition of a small accelerator pedal angle. In adopting this start-off slip control, it was necessary to improve the durability of the lockup clutch facing because the lockup clutch would be used more frequently owing to the expansion of the lockup operating region. For that reason, a new lockup clutch facing was also adopted.

To quicken the engagement of the lockup clutch right after vehicle launch, the pressure is raised to a level just before the operating point of the clutch at the time the driver releases the brake pedal. After the driver depresses the accelerator pedal, the system learns the initial pressure and then raises the pressure according to the optimal ramping set for each accelerator pedal angle so as not to cause any fluctuation in vehicle longitudinal acceleration exceeding the allowable level. Subsequently, the pressure is controlled to match the change in the slip speed of the lockup clutch, while detecting any difference from the target speed. This pressure control procedure achieves a good balance between the lower vehicle speed for lockup operation and other performance parameters such as driveability, noise and vibration.

発進直後からL/Uを作動させるためにブレーキオフ時にクラッチの作動点直前まで油圧を上げ、アクセルを踏んだ後、許容を超えるレベルの車両前後G変動を起こさないよう初期圧を学習し、さらに開度ごとに設定された最適ランプで油圧を上昇させる。その後、目標回転との差分を検知しつつ、スリップ回転変化に応じて油圧をコントロールしていくという油圧制御をすることで、L/Uの低車速化と運転性、音振などの他性能をバランスさせている。

### 3.1.3. Connected feeling の向上

CVT車はエンジン回転上昇と車速上昇との相関が低く、ダイレクトではない評価をうけがちであった。

Connected feelの指標は、加速度に応じた適切なエンジン回転上昇スピードで定義することとした。その指標でCVT7 W/RとCVT7を比較したグラフをFig.7に示す。CVT7 W/Rの方が、車速とエンジン回転が一体となって上昇しており、従来の加速フィールに比べて、よりダイレクト感を創出することを可能にした。

この性能を達成するために、D-STEPという制御を追加した。低开度では、CVT特有の燃費を最優先にした最適燃費効率線を追従する変速を行うが、中高開度のアクセルペダル踏み込み時の加速では、お客さまの加速ニーズに合わせ、車速とエンジン回転上昇に一体感を持たせる。さらに、従来CVTでエンジン回転が最高回転に維持されることの違和感をなくすために、ステップ変速の動きを採用し、リズムカルで心地よくトルク切れのないドライビングフィーリングを実現している。

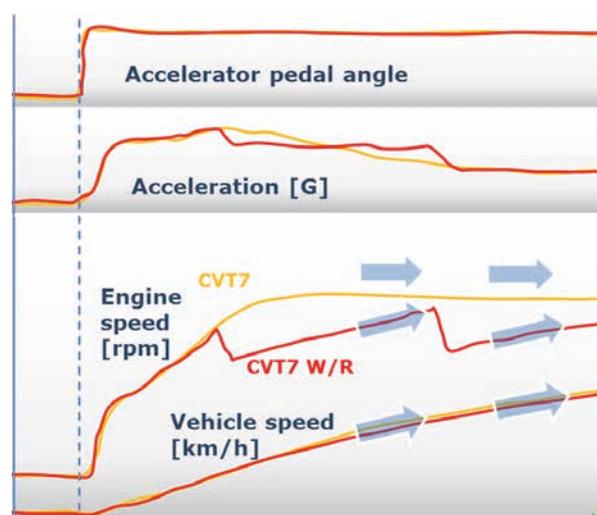


Fig. 7 Comparison of waveforms at re-acceleration between CVT7 and CVT7 W/R

### 3.1.3 Improvement of connected feel

CVT-equipped vehicles have tended to be evaluated as having a disconnected feel because of the low correlation between the rising engine speed and increasing vehicle speed. The index defined for the connected feel is to raise the engine speed at an optimal rate of increase matching the vehicle acceleration. Figure 7 presents a graph that compares the CVT7 W/R and the CVT7 in terms of this index. It is seen that the engine speed and vehicle speed rise together with the CVT7 W/R. This makes it possible to create a more direct feel compared with the acceleration feel obtained with the CVT7.

A new shift control called Dynamic Step Shift (D-STEP) was added to achieve this improved direct feel. At small accelerator pedal angles, the transmission shifts so as to trace the line of optimal fuel efficiency, giving top priority to fuel economy, which is a distinct advantage of CVTs. In acceleration events where the driver depresses the accelerator pedal to a medium or large pedal angle, the vehicle speed and the engine speed rise together with a unified feel in responding to the driver's demanded acceleration. Moreover, step-like shifting action has also been adopted to eliminate the unnatural feeling of the engine speed being maintained at the top speed level, which happened with previous CVTs. As a result, the CVT7 W/R delivers an enjoyable, rhythmical driving feel without any torque discontinuities.

## 3.2 Improvement of fuel economy

### 3.2.1 Expansion of ratio coverage

The ratio coverage of transmissions has continually been expanded in recent years. The CVT7 achieved ratio coverage of 7.3 by incorporating an auxiliary gearbox while at the same time maintaining a compact package. The CVT7 W/R further expands the ratio coverage to 8.7, yet it still retains a package capable of being mounted on small vehicles.

Ratio coverage of 8.0 would be fully sufficient if one only considers the fuel economy test modes applied to small vehicles in various countries throughout the world. However, wider ratio coverage improves fuel economy by allowing a lower engine speed in steady-speed driving at high speeds, particularly in markets where vehicles often cruise at high speed (Fig. 8). It also accommodates frequent use of the lowest gear ratio in repetitive stop-and-go driving in various markets without sacrificing fuel economy. Expanding the ratio coverage has further refined the transmission's

### 3.2. 燃費性能の向上

#### 3.2.1. 変速比幅の拡大

昨今、トランスミッションの変速比幅は拡大してきている。CVT7は7.3の変速比を、副変速機を設けることで達成し、パッケージとの両立を図った。CVT7 W/Rにおいても小型車に搭載できるパッケージを確保したうえで、変速比幅を8.7まで拡大した。

小型車における各国の燃費モードだけを考慮すると、変速比幅8.0あれば十分である。しかし、高速巡航が多い地域ではさらなるワイド化によって高速一定速走行においてエンジン回転数を下げることで燃費を向上することができる (Fig.8)。また発進停止を繰り返すような、ローを使用する頻度が高い市場へも燃費を犠牲にすることなく対応することができる。変速比幅を広げることで燃費と動力性能の両立への貢献にさらに磨きをかけ、多様な市場ニーズに応えることが実現できた。

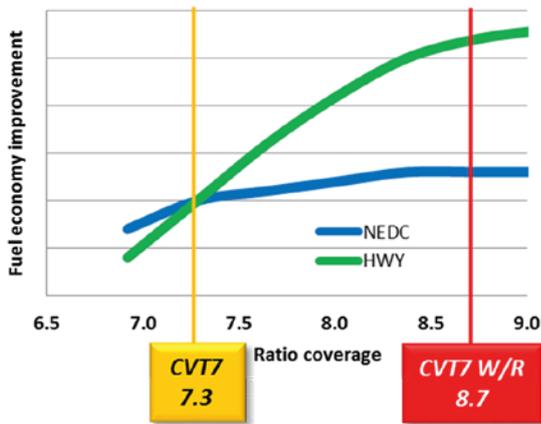


Fig. 8 Relationship between fuel economy improvement and ratio coverage

#### 3.2.2. 伝達効率の向上

トランスミッションの伝達効率向上を目的に以下にあげる技術を採用した。

##### 1) 新型プーリ&ベルト

新たにトルク伝達性を向上させた新型ベルトを採用した。Fig.9に示すように金属エレメントのプーリとの接触面の溝ピッチを細かくすることで、接触面積を向上させ、トルク伝達性を向上している。また、プーリの剛性をあげることで、ベルトの位置や、変速過渡状態においても、安定したトルク容量を確保し、クランプ油圧の低減を実現した。これによりプーリ&ベルトシステムの伝達効率を、主要運転条件において約5%向上した。

contribution to attaining both the desired fuel economy and driveability, thereby enabling the CVT7 W/R to respond to more diverse market needs.

#### 3.2.2 Improvement of transmission efficiency

The following technical measures were adopted for the purpose of improving the transmission efficiency of the CVT7 W/R.

##### (1) New pulley and belt system

A new belt was adopted that further improves the torque transmission capacity. As shown in Fig. 9, the surface of the metal belt elements in contact with the pulleys was designed with a finer groove pitch to increase the area of contact and thereby improve the torque transmission capacity. Pulley stiffness was also increased to ensure stable torque capacity even in transient states of the belt position and during shifting, which allowed the pulley clamping pressure to be reduced. As a result of these measures, the transmission efficiency of the pulley and belt system was improved by approximately 5% under critical operating conditions.

##### (2) Downsizing of oil pump

The oil pump of the CVT7 is built with a flow control valve for circulating fluid internally to generate supercharged pressure that prevents cavitation. However, the orifice friction provided for operating the flow control valve increases internal friction in the oil pump. To reduce pump friction, the flow control valve was discontinued for the oil pump of the CVT7 W/R (Fig. 10). Cavitation that would otherwise occur as a side effect has been successfully inhibited by changing the geometry of the suction port. As a result, oil pump friction by itself has been reduced by approximately 30% compared with that of the oil pump of the CVT7.

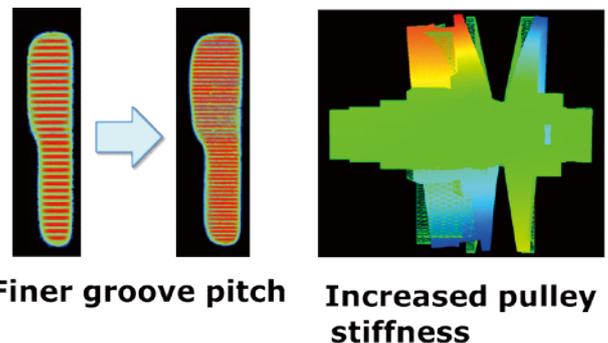


Fig. 9 New belt and pulley system

## 2) オイルポンプの小型化

CVT7のオイルポンプは流量制御弁を採用し、内部循環させてスーパーチャージ圧を発生させることでキャビテーションを抑制していた。一方で、流量制御弁を作動させるためのオリフィス抵抗を設置することでオイルポンプの内部フリクションが上昇していた。そこでCVT7 W/Rでは流量制御弁を廃止した(Fig.10)。副作用であるキャビテーションに対しては、吸入ポートの形状変更によりキャビテーション発生を抑えることに成功した。これにより、オイルポンプ単独でのフリクションをCVT7に対し約30%の削減をすることが可能となった。

## 3) 攪拌ロスの低減

CVT7 W/Rの主断面レイアウトはCVT7の構造を踏襲したが、粒子法によるATF流れの可視化を行い、デフレンシャル(以下DIFF)室の形状最適化、遊星&クラッチ室からのATF排出経路最適化を織り込むことでDIFF部の攪拌抵抗を40%低減した(Fig.11)。

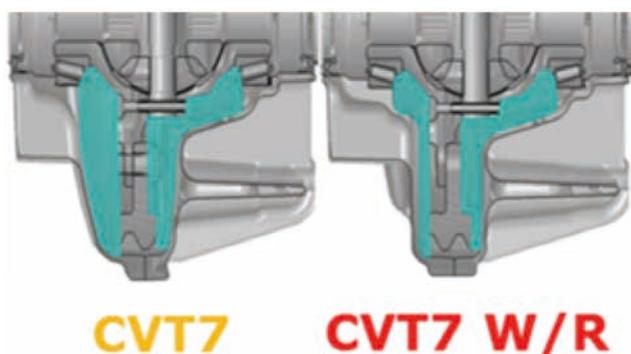


Fig. 11 Reduction of fluid churning resistance

## 4) 低フリクション型シールベアリングの採用

プーリ支持ベアリングの2箇所到低フリクション型シールベアリングを採用した。夾雑物侵入を防止すると同時に、最適なシールすきま量を設定することでシールベアリング部フリクションを、従来のシールベアリングと比較して47%低減した。

## 3.3. 小型車に搭載できるパッケージングの確保

小型CVTに置いて、パッケージングも競争力パラメータのひとつである。ドライバビリティの向上、燃費性能の向上を行ったが、最小限の変更で最大の効果を得ることで、CVT7と同等の搭載性を確保した。ポイントとしては、大き

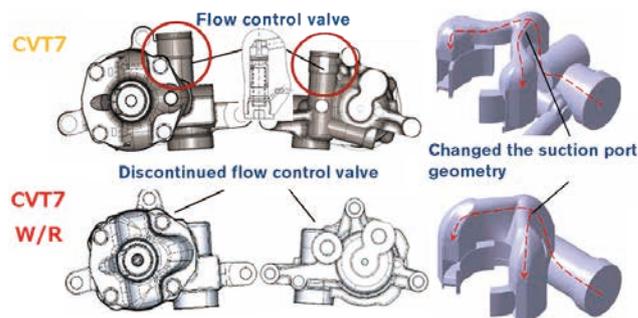


Fig. 10 Oil pump structure

## (3) Reduction of fluid churning resistance

The main cross-sectional layout of the CVT7 W/R continues the structure of the CVT7. However, a particle method was applied to visualize the CVT fluid flow for optimizing the geometry of the differential chamber and the fluid drain passage from the planetary gear and clutch chamber. The incorporation of these measures reduced fluid churning resistance in the differential chamber by 40% (Fig. 11).

## (4) Adoption of low-friction sealed bearings

Low-friction sealed bearings were adopted in two locations as pulley support bearings. The optimal seal clearance was designed to prevent intrusion of foreign particles and at the same time friction at the sealed bearings was reduced by 47% compared with that of the previous sealed bearings.

## 3.3 Assurance of packaging mountable on small vehicles

Packaging is also one of the parameters of competitiveness of CVTs for use on small vehicles. Various measures were adopted to improve driveability and fuel economy, but care was taken to obtain the maximum effects while making minimal changes. As a result, the CVT7 W/R secures the same level of easy mountability as the CVT7. There are two major reasons for that. The first is that, while the volume of the control valve increased due to the adoption of an oil pump without a flow control valve as explained above, among other measures, the increase was kept to a minimum. That was accomplished by revising the clearance between the oil pan and the control valve as well as the groove geometry of the control valve in cooperation with the manufacturing department. The other reason is related to the strategy selected for expanding ratio coverage. With the CVT7, ratio coverage could be expanded not just on the basis of the pulleys, but also by changing the gear ratio of the

く二つがあり、一つは前述の流量制御弁廃止オイルポンプの採用等によるコントロールバルブの容積拡大があったが、生産と連携し、コントロールバルブとオイルパンの隙間、およびコントロールバルブの溝形状の見直しをすることで、容積拡大を最小限に抑えることができた。他の一つはレシオカバレッジの拡大方策の選択である。CVT7は変速比をプーリのみでなく副変速機のギヤ比を変えることでも拡大が可能となる。この2つの選択肢を他の性能要素も含めて比較検討を行った結果、プーリのハイ側を広げることを選択し、これによって軸間距離の変更なくパッケージを維持し、他の性能影響、生産影響も最少化することができた。

#### 4. 性能のまとめ

CVT7 W/Rとして、これら技術を織り込んで下記に示す性能向上を達成した。

- ・ドライバビリティ：ダイレクト感の向上 (Fig.12)  
 発進時はLinearityとConnected feelを向上させ、再加速時は、Connected feelを向上させることで、ダイレクト感を向上させた。
- ・レシオカバレッジの拡大とCVT伝達効率の向上により、  
 車両燃費性能：3%Up (@NEDC mode)させた。

auxiliary gearbox. A study was undertaken to compare these two approaches, including the effects on other performance attributes. As a result, a choice was made to expand the High-side ratio of the pulleys. This made it possible to maintain the desired package size without changing the distance between the pulley shafts, while also minimizing the effects on other performance parameters and production facilities.

#### 4. Summary of Performance Improvements

As a result of incorporating the technical measures explained above, the CVT7 W/R achieved the following performance improvements.

- Driveability: Improvement of direct feel (Fig. 12)  
 The direct feel was improved by enhancing linearity and the connected feel when starting off and also improving the connected feel when re-accelerating.
- Vehicle fuel economy has been increased by 3% in the NEDC test mode by expanding the ratio coverage and improving the transmission efficiency of the CVT.

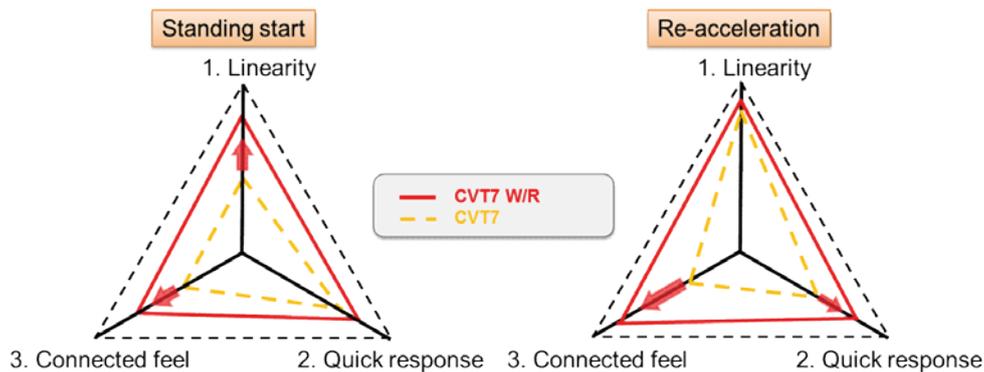


Fig. 12 Comparison of evaluation results for three elements defining direct feel

## 5. マザー級ユニットで初となる海外拠点での生産立上げ

今回のCVT7 W/Rを適用する生産開始時の車両生産国は中国であることから、モノづくりのチャレンジとして、マザー級ユニットで初となる海外拠点での生産立上げを進めた。

実際の生産拠点はジャトコ広州(以下JGZ)となり、日本での生産立上げと同等の良品質を確保するための種々の施策を追加し、同時に車両日程に影響の無いようなリスクマネジメントを行った。

また、購入品も同様に新設部品の多くを現地パートナーサプライヤからの購入としたことを考慮して品質を確保するための特別活動を推進した。

良品質を確保しつつ、かつ計画日程どおりに生産を立上げるために、現地も含めたモノづくり4部門の連携を継続的にとることが不可欠で、今回、正規手配の半年以上前の段階から、定期的に情報のシェアを行い、関連部署が一丸となって迅速かつ確実に課題解決を図るアクションをとった。

## 6. まとめ

CVT7 W/Rは以下アイテムを採用することでコンセプトを実現した。

### 1) ドライブビリティの向上

発進スリップ制御とD-STEP制御の採用によりダイレクト感の向上を実現した。

### 2) 燃費性能の向上

変速比幅の拡大、新型ベルト&プーリの採用、改良型小型オイルポンプの採用、攪拌抵抗の低減、低フリクションシールベアリングの採用等によるトランスミッション効率の向上により、燃費の3%向上を実現した。

### 3) 小型車に搭載できるパッケージングの確保

コントロールバルブの最適配置、新プーリ&ベルト採用によるミニマム変更での変速比幅拡大により、燃費、運転性能向上とともに小型車に搭載可能なパッケージングを実現した。

### 4) マザー級ユニットで初となる海外拠点での生産立上げ

中国・日本共同でのモノづくり4部門の連携、早期から取り組んだ品質向上特別活動により、重要課題の早期抽出と早期解決を行うことができ、ジャトコとして初となる

## 5. First Production Launch of a Mother-class Unit at an Overseas Assembly Plant

At the time production of the CVT7 W/R was launched, this unit was to be mounted on vehicles produced in China. This represented a “monozukuri” (manufacturing) challenge because it was the first time for us to launch production of a mother-class unit initially at an overseas assembly plant.

The assembly plant involved was JATCO Guangzhou Automatic Transmission Ltd. (JGZ). Various additional measures were taken in order to ensure the same level of high quality as that of a production launch in Japan. Simultaneously, risk management was carried out to avoid any impact on the vehicle production schedule.

In addition, special activities were promoted to ensure high quality, considering that many of the newly established parts to be procured would be sourced from local supplier partners in China.

Continuous teamwork among four monozukuri divisions, including those at the local plant, was necessary in order to ensure high quality and also launch production according to the planned schedule. Information was shared regularly from the stage more than six months before the official design release for regular production. The departments involved worked as one united team in taking action to quickly and successfully resolve any issues that came up.

## 6. Conclusion

The development concept of the CVT7 W/R was achieved by adopting the following technical measures.

### (1) Improvement of driveability

The direct feel was improved by adopting start-off slip control and D-STEP shift control.

### (2) Improvement of fuel economy

Fuel economy was improved by 3% as result of improving CVT transmission efficiency by expanding the ratio coverage, adopting a new belt and pulley system, applying a downsized and improved oil pump, and reducing fluid churning resistance, among other measures.

### (3) Assurance of packaging mountable on small vehicles

Packaging mountable on small vehicles was assured along with improving fuel economy and driveability. That was accomplished by expanding the ratio coverage while making minimum changes, thanks to the optimal layout of the control valve and the adoption of the new belt and pulley system.

マザー級ユニットの海外拠点におけるスムーズな生産立上げをJGZで実現することができた。

CVT7 W/Rは、2015年10月に中国で発売された日産ラニア(fig.13)に搭載されている。

本開発にあたり、多大な御協力、ご尽力をいただいた関連部署の皆様に、深く感謝の意を表す。



Fig. 13 Nissan Lannia

(4) First production launch of a mother-class unit at an overseas assembly plant

Close teamwork among four monozukuri divisions carried out jointly between China and Japan and special activities to improve quality that were undertaken from the initial stages of the project made possible the early identification and resolution of critical issues. As a result, we were able to smoothly launch production of the CVT7 W/R at JGX, which was the first time a mother-class unit was put in production initially at an overseas plant.

CVT7 W/R is equipped with Nissan Lannia (fig. 13) launched in October 2015 in China.

The author would like to express his deep appreciation to everyone in the departments involved for their invaluable cooperation and enormous efforts made to develop this new CVT.

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Yoshikuni KATOU



Naotoshi OKUMURA

# 海外プロジェクト活動におけるスムーズな現地立ち上げ

Smooth Local Production Launch in an Overseas Project

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**抄 録** ジヤトコは2015年にJatco CVT7 W/Rを中国で発売を開始した。本稿では、日本と中国とのプロジェクトメンバー間でどのように連携してユニット立ち上げを行ったかを紹介する。

**Summary** JATCO released the new Jatco CVT7 W/R in China in 2015. This article describes how the Japanese and Chinese members of the project team worked closely together to launch production of this new CVT.

## 1. はじめに

## 1. Introduction

ジヤトコは2009年に世界初の副変速機付CVT (Jatco CVT7)を発売し、その後数多くの車種に適用されてきた。すでに世界販売は累計800万台を超え、好評価をいただいている。今回、さらなる高品質化をめざし、Jatco CVT7をベースとして変速比幅8.7を持つワイドレシオバージョン(商品名Jatco CVT7 W/R)を開発した。

JATCO released the world's first CVT with an auxiliary gearbox (Jatco CVT7) in 2009, which has subsequently been adopted on many vehicle models. This CVT is highly evaluated by customers and its cumulative global sales have already surpassed eight million units. With the aim of enhancing product quality further, JATCO developed the Jatco CVT7 W/R, a wide range version engineered around the Jatco CVT7 and featuring ratio coverage of 8.7.

ジヤトコでは過去、新しいCVTユニット開発は日本で開発を行い、日本で生産を開始し、その後海外生産への展開をする手法で進めてきた。しかし今回は急成長する中国での車両販売に合わせて、中国の海外工場生産立ち上げを初めて行った。これは、我々にとっては初めてのチャレンジ活動である。

Previously, JATCO's approach to developing a new CVT was to develop and launch production of the unit in Japan first and then later proceed to begin production at an overseas plant. However, this time production of the CVT7 W/R was first launched at the company's overseas plant in China in connection with the rapid growth of vehicle sales in the Chinese market. That represented an entirely new challenge for us at JATCO.

## 2. ジヤトコ広州の生い立ち

## 2. Growth of JGZ

ジヤトコ(広州)自動変速機有限公司(以下JGZ)は2007年に設立され、2009年より中型CVT JF011Eの生産を開始した。その後、2011年より小型CVTであるJatco CVT7の生産を、さらには2013年からは中型CVTであるJatco CVT8の生産を開始した。創立当初より順調に生産を伸ばし、2015年現在では従業員約2,000人、年間生産85万台と急成長を遂げ、いまやジヤトコのグローバル事業における核となる生産拠点となっている(Fig.1)。JGZは創立以来築き上げてきた、現地スタッフの育成と、平均年齢25才という現地スタッフの若さ、スピード、やる

JATCO Guangzhou Automatic Transmission Ltd. (JGZ) was established in 2007 and began producing the JF011E CVT for application to midsize cars in 2009. Subsequently, JGZ launched production of the Jatco CVT7 for use on small cars in 2011 and then started producing the Jatco CVT8 for application to midsize vehicles in 2013. From the time of its establishment, JGZ has grown rapidly as the production volumes have continued to expand steadily. Now in 2015, it has a workforce of approximately 2,000 employees and is scheduled to produce 850,000 CVTs this

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気に後押しされ、生産能力の拡大と共に力を蓄えてきた。しかしJatco CVT7 W/Rの海外工場での生産立ち上げを成功させるには、JGZにとって経験不足が課題となっていた。

### 3. 海外マザー級ユニット立ち上げへの挑戦

量産ラインへの大規模な混流化改造を伴うプロジェクトは、海外に限らず日本国内でも多くの手戻りの経験がある。加えて海外初の生産立ち上げ、かつユニットの基本構造こそJatco CVT7と類似であるが、Jatco CVT7 W/Rは約30%の部品が新設となるなど、その変更規模の大きさによりマザー級プロジェクトに位置付けられた。

海外生産ラインでの混流改造、マザー級ユニットの海外工場での生産立ち上げというジヤトコでも経験の無いいくつかのチャレンジ活動を行った。

- ・日本と中国を跨ぐ開発-生産-品証-調達連携
- ・過去の経験に基づくリスク低減活動
- ・現地スタッフ主体でのプロジェクト推進
- ・ジヤトコのモノづくりを活かした生産品質評価の先取り
- ・中国パートナーの生産品質確保

これらの取り組みを、過去の経験と知恵を結集し、現地スタッフと共有化し、徹底的にやり抜くことを掲げ、活動を推進した。

### 4. 海外プロジェクト活動の詳細

#### 4.1. 開発-生産-調達-品証の連携

プロジェクトを進めるうえで、開発-生産-調達-品証のモノづくり部門の連携が必要なことは当然のことであるが、今回の海外プロジェクトではさらに部門の壁をなるべく取り除き、垣根を越えて課題の明確化と課題解決のためにタイムリーな進捗管理を図った。

プロジェクトの初期段階で開発が抱える課題を定例のプロジェクトメンバーで常に明確化を行うとともに、情報を一つにし、関係者の知見を早期に注入することを行った。

また、この定例会ではいかに中国でスムーズに立ち上げるかも議論した。

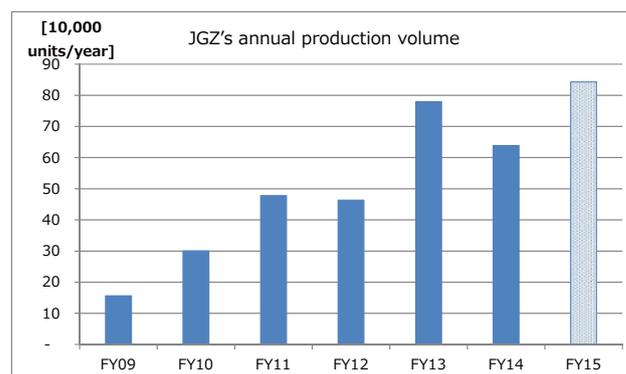


Fig. 1 JGZ's annual production volume

year (Fig. 1). It has now become a core production center in JATCO's global business operations. Since it was founded, JGZ has built up its capabilities along with expanding its production capacity, thanks to the implementation of local staff training early on and supported by the youthfulness (average age of 25), speed and motivation of its local workforce. However, JGZ's lack of experience was an issue that had to be overcome in order to ensure the successful production launch of the Jatco CVT7 W/R at an overseas plant.

#### 3. Challenge to Launch a Mother-class Unit Overseas

In projects involving large-scale changes for mixed production on our mass production lines, we have experienced a lot of reworking not only at overseas plants but also at our production plants in Japan. In addition, because of the enormous scale of the changes to be made, the project described here was positioned as a mother-class project. Among the reasons for doing that, this was the first time for production to be launched initially at an overseas plant. Moreover, approximately 30% of the parts of the Jatco CVT7 W/R were entirely new, though its basic structure resembles that of the Jatco CVT7.

At JATCO, we had never before experienced the restructuring of overseas production lines for mixed production or the production launch of a mother-class unit at an overseas plant. Consequently, a number of challenging activities were undertaken to promote this project.

- Teamwork that straddled Japan and China among R&D, production, purchasing and quality assurance departments
- Risk reduction activities based on past experience
- Promotion of the project primarily by the local staff

#### 4.2. 過去の経験に基づくリスク低減活動

2007年以降の当社CVTの現地化、2011年からの度重なる増産拡張を乗り越えながら現地スタッフのレベルは確実に上がってきた。一方で、現地スタッフ経験の少なさが大きな課題であった。この経験の浅いところを埋める方策として、過去の経験から課題を抽出し、どのようにすすめてらいいかを現地スタッフと共有化し、さらに課題に対して先取りを行い、未然防止、もしくは早期改善を有効的に廻す活動をリスク低減活動として推進した。

手始めとして、生産ラインへ混流改造を行ったことがある過去のプロジェクトの振り返りの知見から、生産準備のプロセスごとに課題を洗い出し課題の見える化に取り組んだ。

検討は技術、製造、検査、保全、生産管理、調達などJGZ内のすべての部門で行い、その活動には現地スタッフも参画した。

一連の生産準備業務に関して検討を行った結果、顕在化した課題は開発時の図面サイマル、改造部品の手配および輸送業務、造り溜め、改造工事の日程管理、改造後の量産復帰、試作、量産前の習熟、そして量産初期品質と増産まで多岐にわたり、総件数は100件を超えていた。

その中でも部門ごとに発生する可能性が高く、早めに回避すべき重要課題を選び出し、先取りの対策および、その実行計画を定めた(Table 1)。

#### 4.3. 現地スタッフ主体でのプロジェクト推進

プロジェクト推進の方向性は見えたが、もうひとつ欠かせない大きな要因がリスクとして挙がっていた。それは実際に業務を担当する現地スタッフの意識の改革と、現地スタッフと日本人スタッフとの課題の共有化である。

従来は日本人スタッフが計画立案から実行までを行い、現地スタッフはその補助的な役割に回ることが多かった。しかし、今回のプロジェクトでは短期間での改造工事と量産復帰を達成するには、多くの現地スタッフの力を結集し、全員が役割を持って主体的に取り組む必要が有ると考え、現地スタッフ主体でのプロジェクトの推進活動とした。

日本人スタッフはリスク課題の検討と低減対策案を作成することで現地スタッフの経験を補う。一方で、現地スタッフは実行と進捗管理を行い、日本人スタッフに報告、そしてアドバイスを繰り返しながら計画を進めることでコミュニケーションを深めた。結果として現地スタッフの意識が

- Advance production quality evaluations utilizing JATCO's "monozukuri" know-how
- Assurance of production quality together with our Chinese supplier partners

Previous experience and wisdom were marshalled and shared with the local JGZ staff in order to fully accomplish these activities and promote the project successfully.

#### 4. Details of Overseas Project Activities

##### 4.1 Teamwork among R&D, production, purchasing and quality assurance departments

Naturally, teamwork among the R&D, production, purchasing and quality assurance departments in the "monozukuri" (development & manufacturing) divisions was necessary for the successful promotion of the project. Because this was an overseas project, additional efforts were made to tear down the walls between departments and to transcend departmental boundaries as much as possible in order to promote timely progress management for clarifying and resolving issues.

In the initial stage of the project, the project members consistently made clear the problems involved in R&D at regular project meetings and injected the know-how of the people concerned at an early point as unified information.

The question of how to ensure a smooth production launch in China was also discussed at these regular project meetings.

##### 4.2 Risk reduction activities based on past experience

Since the start of localization activities for JATCO CVTs at JGZ in 2007, the skill levels of the local staff have risen steadily in the process of successfully handling plant expansion and production increases on multiple occasions since 2011. On the other hand, the limited experience of the local staff was still a formidable issue. As one measure for bridging this lack of experience, we promoted risk reduction activities. Issues were extracted from our own past experience and ideas on how to address them were shared with the local staff. Moreover, we endeavored to anticipate potential issues in advance and undertook effective activities to prevent them from occurring or to implement improvements at an early stage.

To be begin with, a review was made of past projects in which production lines were restructured for mixed production. Based on the resulting knowledge, issues that might occur in each process of the production preparations

Table 1 Activities to reduce project risks

Process	Envisioned risks	Measures taken
Adhering to the line restructuring plan	Insufficient work progress management (resumption delay)	Established a progress meeting system Centralized daily schedule management
	Transport/customs clearance delays (bad weather, sailing cancellation, customs clearance trouble)	Factored risks into transport schedule Listed up previous customs clearance troubles and solutions
	Insufficient preparation of modified parts, jigs, tools, gauges Insufficient production/storage of parts; rust and quality problems	Implemented rules for opening containers and storing parts Adopted 2S(SEIRI, SEITON) storage system for every machine
Resumption of mass production	Insufficient confirmation of quality following line restructuring	Thoroughly implemented an improved quality acceptance inspection method Added a quality confirmation check to daily work plan
	Postponement of plan due to insufficient process capacity following line restructuring	Confirmed process capacity before line restructuring work
	Insufficient spare parts for replacing failed modified parts	Early ordering of listed spare parts and delivery management Storage of parts before line restructuring and use for recovery from unforeseen troubles
Trial production	Delay in feeding back troubles in trial production	Front-loading of trial production GPEC activity for early identification of issues
	Unacceptable dimensions following heat treatment	Advance conduct of strain surveys in Japan and feedback of information on tools for use in China
Vertical production launch	Insufficient confirmation of production line quality	Thorough confirmation by FMEA and validation
	Insufficient measures against mixed production problems	Incorporation of measures for mixed production (detection of different types, selective use of gauges)
	Insufficient learning in training sessions	Preparation of trial plan for work setups/applying loads

高まるとともに、何よりも日本人スタッフと現地スタッフの間で課題が共有化により共通のベクトルを持てたことが大きかった。こうして短期間で生産ライン改造工事、そして量産復帰をさせることができた。

#### 4.4. ジャトコのモノづくりを活かした先取り活動 (GPEC @JGZ)

ジャトコでは、グローバル多拠点同時立ち上げや、生産試作一発良品化(品質玉成の前倒し)を狙いとした、主に金型試作の量産等質化による、量産工法検証活動、通称GPECを試作部中心となって進めている。(GPEC: Global Production Engineering Center の略)

今回のプロジェクトは海外工場での生産立ち上げに加え、生産トライアルを筆頭に毎月連続する試作日程を遵守しながら、日本と中国をまたいで性能実験および品質評価を行い、フィードバックサイクルをいかに短期間で実施するかという大きな課題を背負っていた。

今回の連続する試作日程では、最初の生産試作までにいかに大きな課題を先取りして解決しておくかがカギと考え、ひとつ前の試作ロットを量産工場で生産することを実行した。

試作ロットをジャトコ日本とJGZ中国の2拠点で行うことで、品質の等質化の確認を先取りすることを行った。

日本での試作にはJGZ中国の技術、製造がジャトコ試作部へ出張し、実際に組立作業や、部品検査等の技能、手法を習得し、中国での試作にフィードバックした。そして中国での試作ロットでは、逆にジャトコ試作部のメンバーがJGZへ出張し、組立作業、治具、品質評価法や手順の等質化を確認した(Fig.2)。

were identified and an effort was made to visualize such issues.

Studies were undertaken in all of JGZ's departments, including production engineering, production, inspection, maintenance, production control, and purchasing, among others. The local staff also participated in those activities.

The results of those studies of the series of production preparation activities revealed a total of more than 100 issues extending across a wide range of areas: simultaneous preparation of drawings in the development process, arranging for procurement/transport of modified parts, advance production/storage of parts, management of the work schedule for restructuring production lines, resumption of mass production after restructuring, prototype production, intensive training before mass production launch, quality in the initial stage of mass production and ramping up of production.

Among them, critical issues were selected that were likely to occur in each department and which should be avoided early on. Measures for dealing with those issues were then anticipated and plans for implementing the measures were determined.

#### 4.3 Project promotion primarily by the local staff

While the direction for the promotion of the project became visible, another large and indispensable factor was identified as a potential risk. That concerned changing the consciousness of the local staff, who were actually in charge of the activities, and the sharing of issues by the local staff and the Japanese staff.

In the past, the Japanese staff were responsible for carrying out the work from the planning phase to the execution stage, and the local staff often played a secondary role. However, this project had to be promoted primarily by the local staff in order to restructure the production lines and resume mass production within a short period of time. That would involve marshalling the capabilities of many local staff members, assigning everyone a specific role, and making them primarily responsible for carrying out the activities.

The Japanese staff compensated for the inexperience of the local staff by examining potential risks and devising measures for reducing them. Meanwhile, the local staff were responsible for execution and monitoring progress. They reported to the Japanese staff and obtained the latter's advice repeatedly, leading to closer communication between both sides as the planning proceeded. As a result,

さらに、計画当初は組立作業の訓練道場にパレットと治具を持ちこんで組立を行うことでスタートしたが改造工事を分割し、計画停止日や昼休み時間などわずかなライン停止時間で前倒し対応をするなど地道な活動を積み重ね、ほぼ実際の量産組立ライン、量産加工ラインを用いたALL TOOL試作を達成することができた。

このように中国で試作ロットに取り組み、実際の量産ラインを用いた内製加工および組立作業を通して、CVT先行評価を行った結果、部品図面改訂、設備、治工具、測定具、標準作業書など150件以上の課題を早期に見出すことができ、生産品質の安定化に大きく貢献した。



Fig. 2 GPEC trial production activity by local JGZ staff

#### 4.5. 中国パートナー部品の品質マネジメント

今回のプロジェクトで重要なカギを握るのが、日本の開発陣が意図した図面を正確に中国のパートナーに伝え、モノづくりを行うことだった。

そのために、特に重点的な部品、パートナーを選定し、何度も現地の工場を訪問した。

その結果、パートナーの現地スタッフと日本の開発陣との直接コミュニケーション強化により、設計の意図や重点項目の浸透が図れた。

この活動はJGZ現地スタッフの育成・意識改革が実を進んだことを実感できる活動だった。

### 5. 生みの苦しみ

多くの活動を行ってきて、いよいよ生産試作を行うことになったが、課題はゼロではなかった。

日本と中国のスタッフを巻き込んだ対策会議が連日連

the consciousness of the local staff was elevated, and most importantly, issues were shared between the Japanese staff and the local staff, enabling them to have a common vector, which was critical. In this way, the production lines were restructured and mass production was successfully resumed in a short period of time.

#### 4.4 Advance activities utilizing JATCO's monozukuri experience: GPEC@JGZ

JATCO's prototype manufacturing section is mainly responsible for promoting an activity called the Global Production Engineering Center (GPEC) where mass production methods are verified by achieving quality equivalent to that of mass production primarily in the manufacturing of die/mold prototypes. The aim of GPEC is to facilitate simultaneous production launches at JATCO's global production plants and to achieve excellent quality products in a single production trial so as to advance the refinement of high quality.

Besides involving the launching of production at an overseas plant, another major issue in this project was to shorten as much as possible the feedback cycle for the results of the performance tests and quality evaluations being carried out between Japan and China. At the same time, it was necessary to strictly observe the trial production schedule in which prototype production was continuously carried out every month.

It was assumed that the key to the successful execution of this continuous trial production schedule was to anticipate and resolve as many major issues as possible before the first full-scale production trial. Therefore, it was decided to produce one trial production lot before that stage at mass production plants. A trial production lot was produced at two locations, at a JATCO plant in Japan and at JGZ in China, to confirm in advance whether an equivalent level of quality was obtained.

Members of JGZ's production engineering and manufacturing departments came to JATCO's prototype manufacturing department in Japan for the trial production. They learned the techniques and methods involved in the actual assembly work and parts inspection and fed that knowledge back to the trial production in China. On the other hand, members of JATCO's prototype manufacturing department went to JGZ for the trial production lot produced in China to confirm whether there was an equivalent level of quality in the assembly work, jigs, and quality evaluation methods and procedures.

夜実施され、日本で提案された対策が、すぐに中国側で実行される日々が続いた。

最終的には日本と中国の総力をあげて取り組み、日程どおりに立ち上げることができた。この活動はOne Jatco そのものであった。JGZは日本に距離的に近いことと、日本語でのコミュニケーションが圧倒的に取りやすいことが、さらに我々の助けとなった。

## 6. いざ出荷式

Jatco CVT7 W/Rは、数々の試練を乗り越え2015年7月15日より量産を開始、8月7日には盛大な出荷式を開催した。出荷式にはJGZの全ての部門が参列し、これからのJGZを担う新型CVTへの期待と、これまでの苦勞と達成感を共有出来た(Fig.3)(Fig.4)。

ジャトコ日本およびJGZにとってJatco CVT7 W/Rはチーム力の結晶となり、このプロジェクトを通してOne JATCO、そして世界のトランスミッション会社へ向けてさらに一歩前進した。



Fig. 3 Scene of shipping ceremony



Fig. 4 First Jatco CVT7 W/R built at JGZ

In addition, the initial plan was to start the trial assembly work by bringing in pallets and jigs to the training area for assembly operations. However, as the work of restructuring the lines was divided up, the assembly work training was advanced by taking advantage of times when the lines were stopped briefly, such as during lunch breaks and on days when the planned restructuring work was temporarily suspended. Through the accumulation of such persistent efforts, all tool prototypes were produced using nearly the actual mass machining lines and mass assembly lines.

In the trial production lot produced in China, the actual mass production lines were used to machine parts manufactured in house and to carry out assembly operations. The results of advance evaluations of the CVTs thus produced enabled the early discovery of over 150 issues in the revised part drawings, production facilities, jigs, tools, measuring instruments, standard work sheets and other areas. As a result, that contributed significantly to stabilizing production quality at JGZ.

### 4.5 Quality management for parts procured from Chinese supplier partners

A critical key to the success of this project was to accurately convey to our Chinese supplier partners the intentions incorporated in the drawings created by JATCO's development team in Japan so that they could carry out their monozukuri operations properly. For that purpose, we carefully selected supplier partners, especially for critically important parts, and visited their plants in China any number of times.

As a result, that strengthened direct communication between the staff of the local supplier partners and JATCO's development team and helped to convey the intentions and key points of the part designs. This activity provided a real feeling that the training and change in consciousness of the local JGZ staff had truly borne fruit.

## 5. Birth Pains

After carrying out the many activities described here, we finally reached the trial production stage, but not all of the issues had been resolved yet. Meetings attended by both the Japanese and Chinese staff members to discuss solutions continued every day until late at night. Day after day the corrective measures proposed by the Japanese staff were promptly implemented by the Chinese staff.

## 7. おわりに

今回のプロジェクトでは、垣根を越えた課題の明確化と先取り解決、リスク低減活動を共有しつつ、現地スタッフ主導で進められたことがプロジェクトの成功に対して有効に働いたと考える。

私たちの経験を通して、今後のジャトコグローバルにおける海外生産立ち上げの礎となることを期待したい。

最後に現地スタッフの素晴らしい頑張りとの連携、そしてそれを支えたプロジェクト関係者に絶大な感謝を表したい。

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Fig. 5 Nissan Lannia fitted with the CVT7 W/R

■ Authors ■



Naotoshi OKUMURA



Tsuyoshi TANAKA

Finally, though the combined total efforts of both the Japanese and Chinese staff members, production was launched right on schedule. This activity represented the unity of One Jatco. The geographical closeness of JGZ to Japan and the fact that overwhelmingly communications could be readily conducted in Japanese were also greatly helpful to us.

## 6. First Shipment Ceremony

After overcoming numerous hurdles, mass production of the Jatco CVT7 W/R was launched on July 15, 2015 and a grand first shipment ceremony was held on August 7, attended by all the JGZ divisions. Everyone shared expectations of this new CVT that will carry JGZ forward in the coming years as well as the struggles endured so far and a sense of accomplishment.

For JATCO and JGZ, the Jatco CVT7 W/R represents the crystallization of strong teamwork. Through this project, further progress was made toward One Jatco, and the company took another step forward as the world's number one transmission manufacturer.

## 7. Conclusion

In this project, shared activities transcending departmental boundaries were mounted to clarify issues, implement advance solutions and reduce risks. The promotion of the project primarily under the leadership of the local JGZ staff worked effectively toward its success.

We hope that this experience will serve as the foundation for successful production launches at JATCO's global overseas operations in the future.

Finally, the authors would like to express their profound appreciation to the local JGZ staff for their splendid efforts to do their best and their excellent cooperation as well as to everyone involved for supporting this project.

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# CVT部品用特殊鋼現地化の取り組み

Activities to Localize Procurement of Special Steel for CVT Parts

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**抄 録** 為替変動に影響されにくいモノづくりの観点から、CVTの現地生産が加速する中、その構成部品や材料においても現地化が求められる。本稿では、CVT部品用特殊鋼の現地化の取り組みを紹介する。

**Summary** Local production of CVTs is being accelerated from the standpoint of achieving manufacturing operations unaffected by exchange rate fluctuations. In this regard, there is also a need to localize the procurement of locally produced component parts and materials. This article describes the activities carried out to localize procurement of locally produced special steel for making CVT parts.

## 1. はじめに

## 1. Introduction

グローバルのお客さまのニーズに対応すべく、ユニット・部品の製造工程現地化が進んでいるのは周知の通りだが、その部品を構成する材料に於いても為替変動に影響されないモノづくりの観点から、現地メーカー材料を適用することが望まれている。特にCVTの中でFig.1に示すプーリー・ギヤは材料使用量も多く、材料国産化のメリットが大きいことから、プーリー・ギヤ用特殊鋼の現地化を推進している。

本稿ではジャトコ(広州)自動変速機有限公司(以下、ジャトコ広州と略す)向けのプーリー用鋼材の現地メーカー材採用を既に実現した現地化にあたっての注意点、確認事項などの取り組み内容について述べる。

It is well known that efforts are moving ahead to localize the manufacturing processes of transmissions and parts in order to respond to the needs of global customers. It is also desirable to adopt materials supplied by local manufacturers for making transmission parts from the standpoint of securing manufacturing operations unaffected by exchange rate fluctuations. At JATCO, we are promoting local procurement of special steel particularly for making the pulleys and gears of CVTs. As shown in Fig. 1, these parts require large quantities of materials and significant benefits can be gained by localizing their procurement.

This article describes the activities undertaken to localize procurement of special steel for the pulleys made at JATCO (Guangzhou) Automatic Transmission Ltd. (hereafter JATCO Guangzhou). It focuses on the points requiring attention and the items that needed confirmation in promoting the procurement of materials from local manufacturers whose products have been adopted.

## 2. Quality Required of Special Steel for Pulleys

The quality of the special steels used for automotive parts has a large impact on the performance of the parts. Accordingly, it is necessary to clarify how much influence steel quality has on the performance of auto parts and to maintain the necessary level of quality of the steel

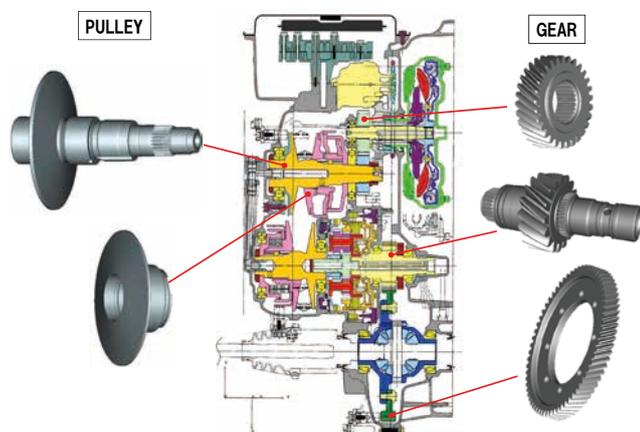


Fig. 1 CVT pulleys and gears made of special steel

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## 2. プーリー用特殊鋼に求められる品質

自動車部品向けの特殊鋼においては、鋼材品質が部品性能に大きな影響を与えるため、鋼材品質が部品性能へ与える影響度を把握し、鋼材品質を維持する必要がある。また、鋼材品質はその製造工程と密接に関係がある (Table 1) ため、納入仕様に対する結果系だけではなく、納入仕様を安定的に製造できる鋼材製造工程になっていることを、実際に現地にて確認する必要がある。

以下、当社CVTプーリー用の特殊鋼に求められる代表的な品質項目と鋼材製造工程での重要確認項目について述べる。

materials used. Moreover, the quality of steel materials is closely related to the manufacturing process (Table1). In addition to verifying that the materials received comply with the delivery specifications, it is also necessary to actually visit the local manufacturer to confirm that its steel manufacturing process is capable of stably producing steel materials possessing the required delivery specifications.

The following sections describe typical quality attributes required of special steel for making CVT pulleys and the important items that must be confirmed in the steel manufacturing process.

Table 1 Relationship between steel manufacturing process and steel quality

									Inspection
Process \ Quality	Electric arc furnace/ Converter	Ladle furnace	Degassing RH/VD	Continuous Casting (Bloom/ Billet)	Heating → Blooming mill	Hot scarfing	Billet inspection (Internal & Surface)	Heating → Bar mill	Bar inspection (Internal & Surface)
◎: Most important process ○: Important process △: Related —: Unrelated									
Center void	—	—	—	◎	—	—	—	—	—
Chemical comp./ Hardenability	—	◎	◎	◎	—	—	—	—	—
Cleanliness	—	○	◎	◎	—	—	○	—	○
Segregation	—	—	△	◎	△	—	—	—	—
Internal flaw	—	—	—	◎	—	—	○	○	◎
Surface flaw	—	—	—	◎	○	○	◎	◎	◎
Decarburizing depth	—	—	—	○	◎	◎	—	◎	—
Hardness (bar)	—	—	◎	◎	○	△	—	◎	—
Dimension/Bend	—	—	—	—	—	—	—	◎	◎
Microstructure/ Hardness(parts)	—	◎	◎	◎	△	△	—	△	—
Grain size	—	—	◎	◎	○	—	—	○	—
Distortion	—	○	◎	◎	△	—	—	△	—
Machinability	—	○	◎	○	—	△	—	△	—

### 2.1. 清浄度(非金属介在物)

鋼材中に製錬～連続 casting の鋼材製造過程で生成または外部から混入する非金属介在物が、鋼材表面近傍に存在すると、部品製造工程での割れや部品の破損につながる可能性があり、注意が必要である。Fig.2に非金属介在物(金属酸化物や硫化物)の例を示す。

### 2.1 Cleanliness (free of non-metallic inclusions)

Careful attention must be paid to the presence of non-metallic inclusions near the steel surface because they can lead to cracks or damage to parts in the parts manufacturing process. Such inclusions can be produced in steel in the manufacturing process from refining to continuous casting or can get mixed in from external sources. Fig. 2 shows an example of such non-metallic incursions (metallic oxides and sulfides).

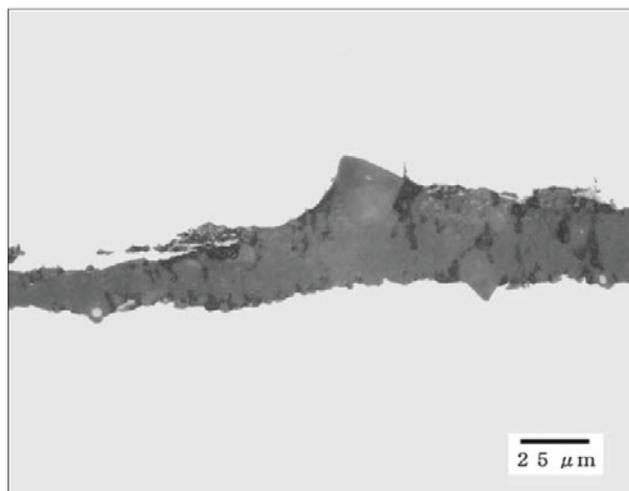


Fig. 2 Example of non-metallic inclusions

鋼の清浄度に影響する工程として、①二次精錬(取鍋製錬, 脱ガス)工程での製錬時間や脱ガス時間, ②連続鋳造工程での鋳片断面積や連続鋳造速度および③鋼片・鋼材内部検査工程が挙げられるが, ASTM E45A法などの介在物検査の結果系だけではなく, ①～③の重要工程の管理項目について現地で確認を行った。

## 2.2. 焼入れ性のばらつき低減

プーリーは熱処理として浸炭焼入れ焼き戻しを実施している。焼入れ時の冷却速度と鋼材の焼入れ性の組み合わせによって、部品の内部硬さをコントロールしているため、鋼材の焼入れ性ばらつきは部品内部硬さ、すなわち部品強度にばらつきを与える要因となる。また鋼材の同一断面内で焼入れ性がばらつく場合においても、焼入れ時の変態量の相違により、熱処理歪による寸法ばらつきが生じることがある。上記より、鋼材の焼入れ性も極力狭幅に管理することが望ましい。

鋼の焼入れ性は、Mn, Si, Crなどの合金元素の含有量ばらつきや偏析により溶解チャージ間・同一横断面内での焼入れ性ばらつきにつながる。今回、通常の焼入れ性試験(JIS G 0561)で規定されている2面での硬さ測定に対し、90°ずらした2面も加えて、同一面内焼入れ性のばらつきを確認した。現地材の試験結果の一例をFig.3に示す。同一面内での硬さばらつきが少ない製造工程であることが確認された。

The following processes influence the cleanliness of steel: (1) smelting time and degassing time in the second refining process (ladle refining and degassing); (2) cross-sectional area of billets and continuous casting rate in the continuous casting process; (3) internal inspection process of billets and bars. In addition to the results of the non-metallic inclusion inspection conducted in accordance with the ASTM E45A method, the control items in the important processes listed in (1) to (3) above were confirmed at the local steel manufacturer's plant.

## 2.2 Reduction of variation in hardenability

The heat treatment applied to pulleys consists of carburizing, quenching and tempering operations. The interior hardness of pulleys is controlled through a combination of the cooling rate during quenching and the hardenability of the steel. Accordingly, variation in the hardenability of the steel is a factor that causes the internal hardness, i.e., internal strength, of pulleys to vary. In addition, there are times when hardenability varies within the same cross-sectional area of the steel. In these cases as well, differences in the degree of transformation during quenching can also cause dimensional variation due to heat treatment distortion. For these reasons, it is desirable to control the hardenability of steel within the smallest possible range of variation.

Variation in the content of alloying elements such as Mn, Si, Cr and others and segregation can lead to variation in the hardenability of steel between manufacturing lot and within the same cross-sectional area. In this work, hardness was measured in the two faces specified in the ordinary hardenability test in the JIS G 0561 standard. In

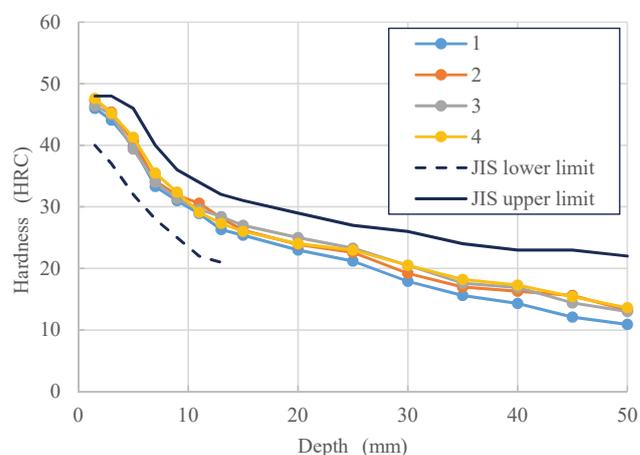


Fig. 3 Results of hardenability test

### 2.3. 表面欠陥

鋼材の表面にFig.4のような疵が存在すると、部品鍛造時に鍛造割れを引き起こし、鍛造製品の歩留まりを悪化させる要因となる。

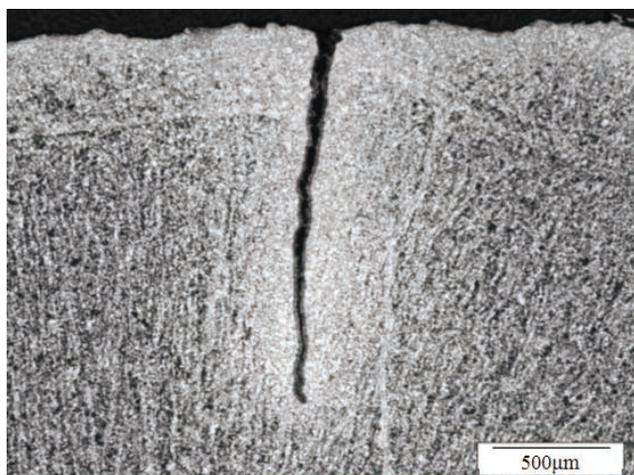


Fig. 4 Example of surface defect (Surface flaw)

鋼材表面の疵発生を抑えるとともに、検査工程での流出防止が重要なポイントとなる。特に現地材採用の際には、鋼片・鋼材の表面疵検査工程、具体的には検査設備の疵検出能力や校正方法・頻度が当社の要求する鋼材品質スペックを保証できる工程であることを確認した。

### 2.4. 耐結晶粒粗大化特性

当社ではCVTプーリーにおいて、浸炭時の高効率化のため、通常ガス浸炭より高温である980℃真空浸炭を実施しているが、この際の懸念事項として旧オーステナイト結晶粒の異常成長が挙げられる。Fig.5のような旧オーステナイト結晶粒異常成長が発生すると、疲労強度や衝撃強度の低下などにつながる場合がある。

異常粒成長を抑制する一つの手段として、AINやNb(CN)などの微細析出物粒子による結晶粒界のピン止め効果(結晶粒界移動の抑止)を利用する手法が取られることがあるが1) 2)、当社ではAIN析出物のピン止め効果による異常粒成長抑制を図っている。鋼材現地化の取り組みでは、現地材と日本材で同等の耐結晶粒粗大化特性を有するか検証するために、熱間鍛造を模擬した加工フォーマスタ試験を実施した。試験方法および与えた熱履歴をFig.6に示す。鋼材より切り出したφ8mm×12mmの円柱状テストピースを1250℃加熱後に60%圧縮変形-放冷の後、恒温焼きなましを模擬した熱履歴を与えた。

addition, two other faces were added by rotating the test piece by 90° and variation in hardenability was confirmed in the same plane. An example of the hardenability test results for locally procured steels are shown in Fig. 3. The results confirmed that this manufacturing process displayed a small degree of variation in hardness in the same plane.

### 2.3 Surface defect

The presence of a flaw in the steel surface like that shown in Fig. 4 can cause a forging crack during the forging process and greatly reduce the yield of steel forgings.

Suppressing the occurrence of such surface flaws and also making sure that they are not overlooked and passed on in the inspection process are crucial points here. Before adopting locally produced steel, we confirmed that the surface flaw inspection process for steel billets and bars was capable of assuring the steel quality specifications required by JATCO. Specifically, we confirmed the capacity of the inspection facilities for detecting surface flaws, method of correcting them and their frequency of occurrence.

### 2.4 Grain-coarsening resistance characteristic

At JATCO, we apply a vacuum carburizing process to CVT pulleys at a carburizing gas temperature of 980 °C. That is higher than the ordinary gas temperature and is used to increase carburizing efficiency. One concern here is that the original austenite grains might grow abnormally during the carburizing process. An example of such abnormal austenite grain growth is shown in Fig. 5. Such grain coarsening can lead to a decline in fatigue strength and impact strength, among other problems.

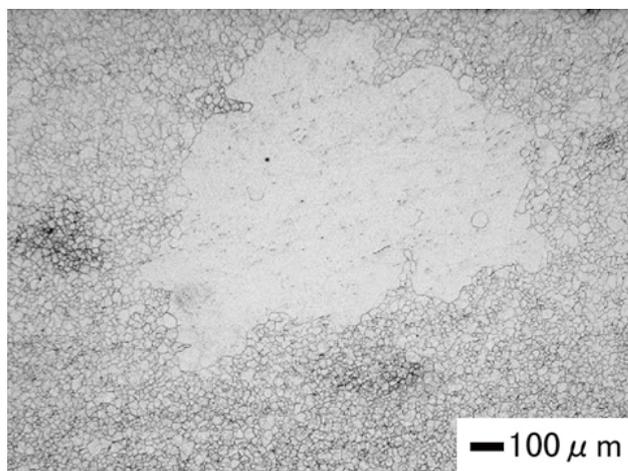


Fig. 5 Example of grain coarsening

得られたテストピースを950～1020℃真空浸炭し、旧オーステナイト粒を光学顕微鏡にて観察した。

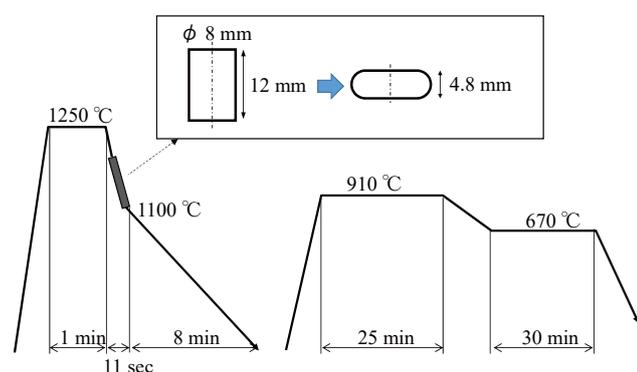


Fig. 6 Heat pattern of formaster test

テストピースのAIN量と結晶粒粗大化が発生した浸炭温度の関係をFig.7に示す。

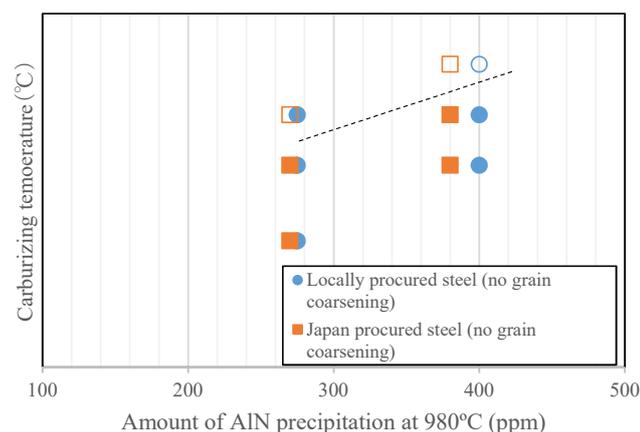


Fig. 7 Relationship between the amount of AlN precipitation and carburizing temperature

ここでAIN量は便宜上980℃におけるAIN析出量とし、(1)式のLeslieが示したAl, Nの鋼中溶解度積<sup>3)</sup>とAIN化学量論組成から以下の(2)(3)式を用いて、鋼中のAl, N含有量より計算された。

$$\log [Al][N] = 1.03 - 6770/T \quad \cdots (1)$$

$$Al - [Al] = 0.658 <AlN> \quad \cdots (2)$$

$$N - [N] = 0.342 <AlN> \quad \cdots (3)$$

ここで

Al, N: 鋼中のAl, N総量

[Al], [N]: 鋼中に固溶しているAl, N量

<AlN>: AlN析出量

とする。

One method of controlling such abnormal grain growth is to use the pinning effect exerted by ultra-fine precipitates of AlN or Nb (CN) on grain boundaries to prevent them from moving.<sup>(1-2)</sup> At JATCO, we use the pinning effect of AlN precipitates to suppress abnormal grain growth.

In connection with the adoption of locally produced steel, we verified whether it possessed the same grain-coarsening resistance characteristic as that of steel procured in Japan. That was done by conducting a formaster test which simulated the hot forging process.

The test method and heat pattern applied are illustrated in Fig. 6. A cylindrical test piece, 8 mm in diameter and 12 mm long, was cut from a steel bar and heated to 1250°C followed by 60 % compression deformation and cooling. After that, the heat pattern applied simulated isothermal annealing. The test piece thus obtained was then vacuum carburized at 950°C - 1020°C and the austenite grain size was observed with an optical microscope.

Fig. 7 shows the relationship between the amount of AlN precipitation and the carburizing temperature at which grain coarsening occurred for steels procured locally and in Japan.

The Al and N contents of the steel samples were calculated using Eq. (3) proposed by Leslie et al. for the solubility product of Al and N in steel (3) and Eqs. (2) and (3) derived from the stoichiometric composition of AlN. Here, for convenience, the amount of AlN precipitation was assumed to be that at 980°C.

$$\log [Al][N] = 1.03 - 6770/T \quad \cdots (1)$$

$$Al - [Al] = 0.658 <AlN> \quad \cdots (2)$$

$$N - [N] = 0.342 <AlN> \quad \cdots (3)$$

where

Al, N: total content of Al and N in the steel

[Al], [N]: amount of Al and N dissolved in the steel

<AlN>: amount of AlN precipitation

As shown in Fig. 7, a comparison of the locally procured steel and Japan-procured steel at the same level of AlN precipitation showed that there was no significant difference in the temperature at which abnormal grain growth occurred. This confirmed that they possessed the same grain-coarsening resistance characteristics.

Fig.7に示されるように、現地材と日本材とで同一のAIN析出量で比較すると、異常粒成長の発生温度に有意差がなく、結晶粒粗大化特性は同等であることが確認された。

### 3. まとめ

以上、CVTプーリー用の鋼材を現地化するにあたっての代表的な重要確認項目と現地での確認結果の一部を紹介した。本取り組みでは、現地材の鋼材品質の確認とともに、製造工程も当社の要求仕様を満足し、その品質を維持可能な工程であることを十分確認したうえで、ジャトコ広州向けのCVT7のプーリーにおいて鋼材の現地化を実現した。

### 4. 謝辞

本取り組みを遂行するにあたって、多大なご協力をいただいた関係各位の方々に、心より感謝する。

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### 3. Conclusion

This article has described typical examples of important items that were confirmed in connection with the adoption of locally procured steel for making CVT pulleys and presented some of the locally confirmed results. The activities undertaken confirmed the quality of the locally produced steel and also that the local manufacturing process satisfied JATCO's required specifications. After fully confirming that the local process was capable of maintaining the required quality, it was decided to adopt the locally produced steel for making CVT7 pulleys at JATCO Guangzhou.

### 4. Acknowledgments

The authors would like to express their heartfelt appreciation to everyone concerned who made invaluable contributions to the execution of the activities described here.

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# 現地調達部品の拡大とその品質保証の強化

Expansion of Local Parts Procurement and Enhancement of Quality Assurance

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**抄 録** 本稿は、Jatco CVT7 W/R(以下、CVT7 W/Rと称する)プロジェクトにおける現地調達部品の拡大に関する取り組みについて報告する。部品の現地調達化を推進するための活動として、部品調達先検討のフロントローディング、現地調達率目標値の設定やその達成管理、目標達成方策としての現地工場での受け入れ目標コストの設定を行った。これに加えて、現地調達部品の品質保証の強化策として、品質業務のフロントローディング、サイマル活動、工程監査、現場確認、生産負荷対応能力の確認などを行った。その結果、高いレベルの現地部品調達率と品質を両立することができた。

**Summary** This article describes the activities undertaken to expand local procurement of purchased parts in the Jatco CVT7 W/R (CVT7 W/R) project. These activities to expand local procurement of parts included the front loading of the investigation of parts suppliers, the setting of targets for local procurement ratio and target attainment management, and the setting of cost targets based on receipt at JATCO's local plant as a measure for promoting target attainment. In addition, measures were taken to strengthen quality assurance for locally procured parts. Among other things, these measures included the front loading of quality assurance work, simultaneous activities, process audits, confirmation of production workplaces, and confirmation of suppliers' capacity to handle the production load. As a result, high local procurement ratio and high quality levels were both attained.

## 1. はじめに

## 1. Introduction

購入部品の現地調達の拡大は、コスト削減等種々の観点から、CVTユニットの海外対応における重要な取り組みの一つである<sup>(1)</sup>。本稿ではCVT7 W/Rプロジェクトにおける購入部品の現地調達の取り組みについて報告する。

Expanding local procurement of purchased parts is one of the key activities for promoting overseas production of CVTs from various viewpoints such as cost reductions. This article describes the efforts undertaken to expand local procurement of purchased parts in the CVT7 W/R project.

## 2. 現地調達部品の拡大

## 2. Expansion of Locally Procured Parts

現地部品の採用推進は、部品輸入の際に必要な物流費用や関税費用などの削減の観点から、コスト削減の重要方策のひとつである<sup>(2)</sup>。一般的に、トランスミッション部品を中国にて海外から輸入すると、物流費や通関手数料等で部品代の5%程度、輸入関税は6%から10%程度が必要と言われている。このような部品輸入に関する諸費用は、現地部品を採用すれば、それに見合った削減が可能となる。

Promoting the adoption of local parts is an important cost reduction measure from the standpoint of reducing logistics costs, customs duties and other costs that are necessarily incurred when parts are imported. When importing transmission parts into China from overseas, it is said that logistics costs, customs clearance fees and other related costs generally amount to around 5% of the price of the parts and import duties from 6% to 10%. If local parts are adopted, cost reductions can be achieved that are equivalent to these various expenses involved in importing parts.

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また、部品を現地調達することにより、量産段階における海上輸送在庫の削減効果や、設計変更の採用までにかかるリードタイムを短縮できる効果も期待することができる。

### 3. CVT7 W/Rとしての現地調達部品の拡大

CVT7 W/Rプロジェクトにおいても、従来のプロジェクトと同様に、プロジェクト初期のタイミングで部品調達先の選定を行った。本プロジェクトでは部品の現地調達の拡大を図るため、従来の方法に加えて、以下の取り組みを実施した。

- ① 部品調達先検討のフロントローディング
- ② 現地調達率目標値の設定とその達成管理
- ③ 現地工場での受け入れ目標コストの設定

以下、それぞれの活動内容を説明する。

#### 3.1. 部品調達先検討業務のフロントローディング

調達先選定プロセスのごく初期段階において、部品の現地調達可否の検討を先行的に行った。その内容としては、新たな部品調達先の発掘活動や既存の現地調達先における新たな部品種の生産可能性検討等である。

これによって、現地調達先候補先の拡大を図ることができた。この活動によって作成された現地調達候補先リストが、その後の現地調達先の決定プロセスにおいて重要な役割を果たした。

#### 3.2. 現地直達率目標値の設定と達成管理

本プロジェクトでは、明確な現地調達率目標を設定し、その達成管理を実施した。達成管理の具体的な方法は、調達先選定の準備段階において、達成見通しの数値化を行い、その結果をフィードバックする、というものである。

この取り組みにより、調達先選定初期の段階から、精度のよい達成度予測、ならびに管理を行うことができた。また、達成度予測の見える化とその共有化により、関係部門間での連携も密に取ることが可能となり、コミュニケーションも円滑に行うことができた。

Other benefits that can also be expected from local procurement of parts include the reduction of inventory in marine transit at the mass production stage and the shortening of lead time to the adoption of design changes.

### 3. Expansion of Locally Procured Parts for the CVT7 W/R

Similar to other projects in the past, suppliers of purchased parts were selected at an early stage of the CVT7 W/R project. In order to expand local procurement of parts in this project, the following activities were undertaken in addition to the methods used previously.

- (1) Front loading of the investigation of parts suppliers
- (2) Setting of targets for local procurement ratio and target achievement management
- (3) Setting of cost targets based on receipt at JATCO's local plant

The details of each of these activities are explained below.

#### 3.1 Front loading of the investigation of parts suppliers

At a very early stage in the process of selecting suppliers an advance study was made of whether local parts procurement was possible or not. The details of the study included efforts to discover new parts suppliers and investigations of whether existing local suppliers were capable of producing other new types of parts.

As a result, we were able to expand the number of local supplier candidates. Through these activities a list of potential local supplier candidates was prepared. That list subsequently played an important role in the process of determining local suppliers.

#### 3.2 Setting of targets for local procurement ratio and target achievement management

Clear targets were set for local procurement ratio in this project and steps were taken to manage the achievement of the targets. As a concrete measure for managing target achievement, the prospects for attaining the cost targets were quantified at the preparation stage of supplier selection and the results were fed back to the selection process.

These efforts made it possible to accurately project the degree of target attainment at the early stage of supplier selection and to carry measures for managing target achievement. In addition, the target attainment projections were visualized and shared, which facilitated closer collaboration among the departments involved as well as smooth communication.

### 3.3. 現地工場での受け入れ目標コストの設定

部品調達先選定プロセスにおいては、部品コストの調達目標値を設定して、それをクリアすることが要求されるが、本プロジェクトでは、この部品コストの調達目標値について、中国現地工場着ベースとすることとした。つまり、部品調達先として、中国現地のサプライヤを選定すれば、物流、通関手数料、輸入関税にかかる費用分を、海外のサプライヤから輸入するケースよりも、目標値をクリアするという観点において有利とできる仕組みである。

これらの取り組みの結果、CVT7 W/Rでは、従来機種に比べ部品の現地調達率を約10%向上することができた。

## 4. CVT7 W/R 現地調達部品品質保証の強化

購入部品の現地調達化の拡大に伴い、使用言語や文化的な差異を背景としたコミュニケーション課題、地理的な距離を背景としたリードタイム課題等により、品質保証活動はより困難になってきている<sup>(3,4)</sup>。

以降の章では、CVT7 W/Rプロジェクトにおける、現地調達部品の品質保証活動について、ジャトコ(日本)ならびにジャトコ(広州)で実施した、新たな取り組みの内容を説明する。

その概要は以下である。

#### ①品質業務のフロントローディング

### 3.3 Setting of cost targets based on receipt at JATCO's local plant

In the process of selecting parts suppliers, targets were set for parts procurement costs, and it was necessary to attain those targets. In this project, the targets for parts procurement costs were defined on the basis of arrival at JATCO's local plant in China. In other words, selecting local Chinese companies as parts suppliers would be more advantageous for achieving the cost targets than importing parts from overseas suppliers because of the elimination of costs for logistics, customs clearance fees and import duties.

As a result of adopting this system, local procurement ratio of parts for the CVT7 W/R were improved by approximately 10% compared with the ratio for previous CVT models.

## 4. Strengthening of Quality Assurance for Locally Procured Parts of CVT7 W/R

Expanding local procurement of purchased parts made quality assurance activities much more difficult owing to communication issues stemming from language and cultural differences and lead time issues related to geographical distances, among other things.

The following sections explain the efforts newly undertaken by JATCO (Japan) and JATCO (Guangzhou) to strengthen quality assurance activities for locally procured

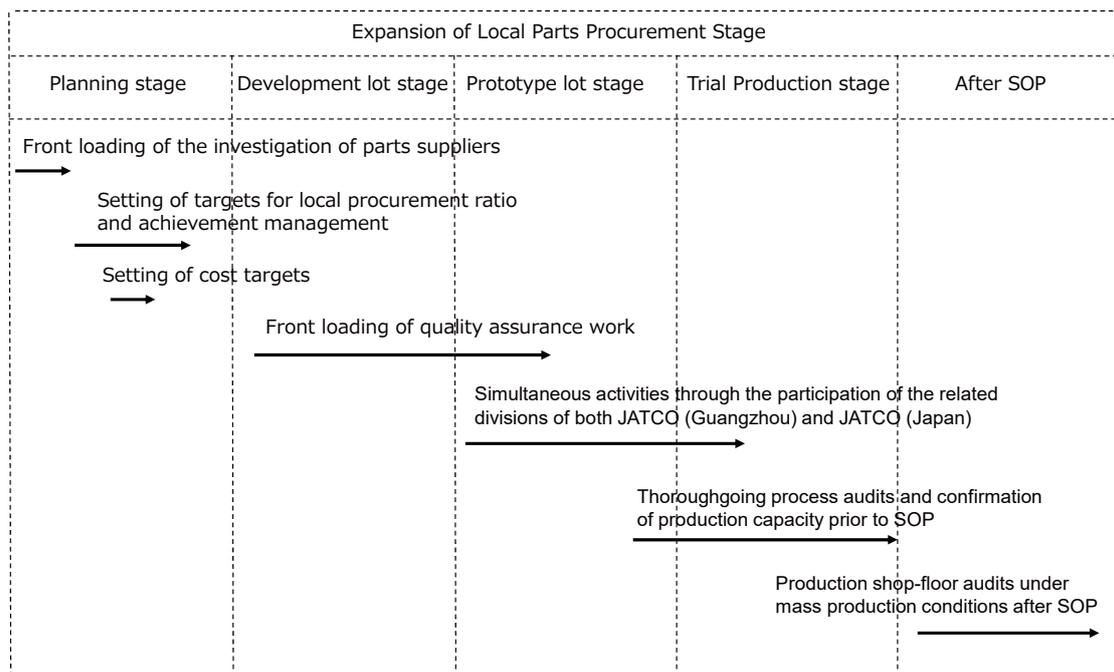


Fig. 1 Key points of activities and project schedule

- ②ジヤトコ(広州)およびジヤトコ(日本)の調達, 品質, 開発, 生産各部門参加のサイマル活動
  - ③SOP(Start of Production; 生産開始を意味する. 以下, SOP)前での徹底した工程監査と生産負荷対応能力の確認
  - ④SOP後の量産状態での現場監査の計画
- なお, これら取り組みの内容とプロジェクトスケジュールとの相互関係は, Fig.1に記載するとおりである。

#### 4.1. 購入部品品質業務のフロントローディング

従来の現地調達部品の品質保証活動は, ジヤトコ(日本)にて生産を開始した後に, 現地に業務移管する方法で進めていた. 従来はこの方法でも十分な品質保証が可能であったが, CVT7 W/Rにおいては, 現地調達部品の比率が高く, また当然ながら, 現地の部品サプライヤとの連携は中国国内での対応となるため, ジヤトコにおける品質業務も, ジヤトコ(広州)主体で遂行できるようにした. つまり, 品質業務のフロントローディングとして, プロジェクトの比較的早期の段階からジヤトコ(広州)への業務移管とジヤトコ(日本)-ジヤトコ(広州)の協業を進めてきた.

具体的には, ジヤトコ(広州)の中国人スタッフにより, プロジェクトの品質業務を実施する際には, 日本側から, よりきめ細かくフォローアップする体制をとった. つまり, 日中双方からの出張対応などを行うことで, OJTにて中国人スタッフのレベルアップを図っていった. またその後も, 定期的に業務の進捗確認を行い, プロジェクト全体の進行や, 課題, ならびに必要な実施事項を明確にするなどした. その結果, 中国人スタッフが品質業務を抜け漏れなく, かつ主体的に遂行することができるようになった.

#### 4.2. 購入品サイマル活動

現地調達部品の採用に向けては, 調達部門, 品質保証部門だけでなく, 開発部門, 生産技術部門とも連携し, 中国現地サプライヤの生産工程を確認した. 加えて, サプライヤの工程設計の考え方についても, 確認, 意見交換を実施することで, ジヤトコ(日本), ジヤトコ(広州)ならびにサプライヤの英知を結集して, 品質保証活動を推進することができた. 具体的には, 関係各部門メンバーから構成されるスペシャルチームを編成して, サプライヤ現地工場の現場にて, 生産準備状況および現物を確認した.

parts in the CVT7 W/R project. An outline of these efforts is given below.

- (1) Front loading of quality assurance work
- (2) Simultaneous activities through the participation of the purchasing, quality assurance, development and manufacturing divisions of both JATCO (Guangzhou) and JATCO (Japan)
- (3) Thoroughgoing process audits and confirmation of capacity to handle the production load prior to the start of production (SOP)
- (4) Planning of production shop-floor audits under mass production conditions after SOP

The interrelationships between the details of these efforts and the project schedule are outlined in Fig. 1.

#### 4.1 Front loading of quality assurance work for locally procured parts

Previously, quality assurance activities for locally procured parts were carried out by transferring the work involved to the local plant following the launch of production at JATCO (Japan). This conventional method achieved ample quality assurance in the past. However, for the CVT7 W/R, the percentage of locally procured parts was higher and coordination with local parts suppliers would be handled in China. That meant JATCO (Guangzhou) would naturally be mainly responsible for conducting the quality assurance work in JATCO's organization. In short, the front loading of quality assurance work involved transferring the work to JATCO (Guangzhou) at a relatively early stage in the project and the joint conduct of the work by JATCO (Japan) and JATCO (Guangzhou).

Specifically, a system was established whereby the Japan side closely followed up on the quality assurance work done in the project by the Chinese staff at JATCO (Guangzhou). This was accomplished through business trips by both the Japanese and Chinese employees involved in order to improve the skills of the Chinese staff through on-the-job (OJT) training. Subsequently, the progress of the quality assurance work was periodically confirmed and the progress of the entire project, issues and the necessary measures to be implemented were made clear. As a result, the Chinese staff became able to execute the quality assurance work fully on their own initiative and without any omissions.

また、SOP後に運用予定となっている作業表や工程表についても、入念に確認した。これにより、従来以上の多岐にわたるレベルでの課題抽出や、細やかな工程改善を行うことが可能となった。

#### 4.3. SOP前での徹底した工程監査と負荷能力の確認

サプライヤにおける生産品質確保のための方策として、工程監査を実施することは、グローバルジャトコの標準である。この工程監査活動において、CVT7 W/Rでは新たな取り組みとして、SOP前に、サプライヤにおける工程の負荷能力を現地で検証し、生産数量が増加した際の課題抽出とその対応策の事前確認を実施した。すなわち、生産前の工程監査とSOP前の複数回の工程監査を実施することとなり、これを円滑に行うために、監査を実行するジャトコ(広州)品証部門の中国人スタッフの監査スキルのレベルアップも課題となった。

これを解決するために、中国人スタッフ向けの事前トレーニングを、日本の品質保証部門内にて実施した。その結果、従以上にきめ細かな内容についても、現地スタッフによる主体的な監査が、現地にて現物を確認しながら進めることができた。

また、Tier2、Tier3サプライヤについても、Tier1サプライヤと連携して工程の現場確認を実施し、品質保証、工程保証の準備を円滑に進めることができた。なおかつ、監査スキルアップトレーニングの成果により、現地スタッフが見出した課題も多岐に渡った。

#### 4.4. SOP後の量産状態での現場監査

CVT7 W/Rはジャトコ(広州)において生産中であり、現地調達部品についても、すでに生産は開始されている。CVT7 W/Rでは、いままでにない取り組みとして、量産状態での再度の現場監査を実施した。

この活動は、SOP前工程監査の残課題について、現場にて確実に完了確認することを主目的とするものであるが、ジャトコ(広州)工場の監督者層も同行し、中国現地サプライヤの現場管理の状態確認や品質保証体制の再確認も、あわせて行った。

#### 4.2 Simultaneous activities for locally procured parts

In the course of adopting locally procured parts, not only the purchasing division and the quality assurance division but also the R&D division and the production engineering division worked together to confirm the production processes of the local Chinese suppliers. In addition, the suppliers' thinking regarding process design was confirmed and opinions were exchanged, making it possible to promote quality assurance activities through the combined wisdom and knowhow of JATCO (Japan), JATCO (Guangzhou) and the suppliers.

Specifically, a special team was formed comprising the main members from each of the related divisions. The team visited the production workplaces of the local suppliers and confirmed the status of their production preparations and actual products. Moreover, the work sheets and process charts scheduled to be used after SOP were carefully checked. These efforts made it possible to identify issues over a wide range of levels and to implement more fine-tuned process improvements than ever before.

#### 4.3 Thoroughgoing process audits and confirmation of capacity to handle production load prior to SOP

A standard procedure at JATCO's global operations is to conduct process audits as a means of assuring the production quality of suppliers. New efforts were made in the process audit activity for the CVT7 W/R. Prior to SOP, the suppliers' capacity to handle the process load was verified on site, and efforts were made to identify issues that might occur when production volumes were increased as well as to confirm solutions in advance. That involved conducting process audits multiple times before SOP. One issue that had to be addressed to accomplish that was to improve the auditing skills of the Chinese staff concerned in the quality assurance division at JATCO (Guangzhou) so that they could conduct audits smoothly.

To resolve that issue, training for the Chinese staff was conducted in advance in the quality assurance division at JATCO in Japan. As a result, the local Chinese staff were able to take the initiative to conduct more detailed audits than before in confirming the actual circumstances and products at the local suppliers in China.

In addition, they worked together with the Tier-1 suppliers to confirm the production workplaces of the Tier-2 and Tier-3 suppliers and to proceed smoothly with preparations for process assurance and quality assurance. It should be noted that the local Chinese staff were able to

## 5. まとめ

これらの活動により、CVT7 W/Rにおける現地調達部品の拡大ができ、かつ、品質レベルは日本でのSOPの事例と同等の高いレベルを確保することができた。

なお、本稿にて説明した活動は、その基準化と、次期プロジェクトへの反映もあわせて推進中である。

本活動にあたり、多大なるご協力をいただいた関係サプライヤの方々に感謝の意を表す。

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discover a wide range of issues as a result of the auditing skills training they received.

### 4.4 Production shop-floor audits of mass production conditions after SOP

The CVT7 W/R is now being produced at JATCO (Guangzhou) and production of locally procured parts is already under way. For the CVT7 W/R, workplace audits were conducted once again under mass production conditions, something that has never been done before.

The main purpose of those audits was to confirm that remaining issues at the time of the pre-SOP process audits had been completely and effectively addressed in the production workplaces. Supervisors at JATCO (Guangzhou)'s plant also accompanied the auditors to confirm the workplace management conditions at the local Chinese suppliers and also to reconfirm their quality assurance systems.

## 5. Conclusion

The foregoing activities made it possible to expand local procurement of parts for the CVT7 W/R and to ensure a high level of quality equal to that attained at SOP in Japan.

It should be mentioned that the activities described here will be standardized and efforts are also under way to reflect them in next-generation projects.

We would like to express our appreciation to all of the suppliers involved for their invaluable cooperation with these activities.

## ■ Authors ■



Masayuki SATO



Takafumi SUZUKI

# 海外プロジェクトとしての品質保証の強化

Strengthening of Quality Assurance in an Overseas Project

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**抄 録** ジヤトコは高品質な商品をお客さまに提供するため、自動車メーカーやサプライヤと連携した継続的な品質改善活動を実施している。

ここでは海外市場での品質課題を、早期に解決にするための活動について紹介する。

**Summary** JATCO carries out quality improvement activities continuously in close cooperation with automakers and suppliers in order to deliver high-quality products to our customers. This article describes examples of activities that were implemented for quickly resolving quality issues in an overseas market.

## 1. はじめに

市場が拡大する中国市場において品質向上の要求は、ますますその重要度を増している。

本稿では、特に中国市場における品質改善活動で具体的に取り組んだ事例について報告する。

## 1. Introduction

Demands for improvement of quality are continually assuming greater priority in China where the vehicle market keeps on expanding. This article describes specific examples of activities deployed to improve quality especially in the Chinese market.

## 2. 新型CVT7(CVT7 W/R)市場投入前の説明会

Jatco CVT7 W/R(以下、CVT7 W/Rと称す)は燃費や品質の向上を目的にさまざまな新技術を織り込んでいる。その新技術や特徴について、自動車メーカーのサービス部門を対象に説明会を初めて開催した。この説明会は、自動車メーカーのサービス部門の方々が日頃感じているCVTの疑問を解決していただき、市場からの問い合わせに迅速かつ十分な対応が出来るようにする目的で開催した。

当日は、既存ユニットであるCVT7に対する改善点による燃費アップ、発進時のレスポンスの速さ、また新機構となるアイドルリングストップ制御や品質改善内容および信頼性向上内容などの盛り沢山の説明を行った。

参加者からは専門知識に関する質問も多数寄せられ、日頃感じていたCVTの疑問も解決し、CVTに対する理解を深めていただくことが出来た。

## 2. Briefing Prior to Market Launch of the New CVT7 W/R

The CVT7 W/R incorporates various new technologies for the purpose of improving fuel economy and quality. JATCO conducted its first-ever briefing for the service division of automaker customers to explain these new technologies and their features. This briefing was held to dispel any doubts that people in the service division feel about CVTs in the course of their daily work. Another purpose was to enable them to respond promptly and fully to any inquiries they receive from customers or other people.

A wide range of detailed explanations were given on the day of the briefing. We explained the improvements made to enhance fuel economy and provide faster response for vehicle launch compared with the existing CVT7. Stop-start control was presented as a new mechanism, and the details of measures taken to improve quality and reliability were explained as well.

The attendees also asked many questions regarding specialized knowledge. Answering their questions helped to dispel doubts they routinely have about CVTs and deepened their knowledge of CVT technology (Fig. 1).

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Fig. 1 Training scene for the new CVT7 W/R

### 3. DR-V Activity

An instrumented drive recorder vehicle (DR-V) for making automatic judgements has been newly deployed at local vehicle assembly plants to confirm the quality of all vehicles as they come off the assembly line (Fig. 2). This is done in addition to the final testing at the CVT assembly plant and the quality confirmation testing at the vehicle assembly plant. The aim of this DR-V activity is to deliver peace of mind, safety and satisfaction to our customers.

This DR-V activity makes use of completely new automatic judgement functionality to inspect all vehicles in driving tests. At the time an automatic judgment is made, the system records what the driving conditions are, which signals act as triggers and other relevant phenomena that lead to the judgment. It also assesses whether the driving pattern for satisfying the test conditions exerts any influence on the vehicle production schedule and whether safety is properly assured. The driving conditions were determined through repeated trial and error done again and again. Moreover, once the driving conditions were finalized, the inspectors (test drivers at the vehicle assembly plant) underwent thorough simulated driving education and training repeatedly until they were able to drive stably under the defined conditions. Everyone involved worked closely together in unison to overcome any issues that were discovered until the activity was successfully completed.

The DR-V activity makes use of actual data recorded from actual vehicles at the assembly plant to ensure that the attractive quality created in the development process is reliably built into the vehicles, whether the production volume is several thousand or several ten thousand units.

### 3. DR-V活動について(車両工場での全数確認)

#### DR-V : Drive Recorder Vehicle

お客さまへ安心/安全/満足をお届けするため、ユニット工場でのファイナルテスト、車両工場での品質確認試験に加えて、今回新たにDR-V(自動判別計測器)を搭載したオフライン車両の全数品質確認を実施した。

このDR-V活動では、全く新しい自動判定機能を活用して車両の全車走行監査を行った。この自動判定をする際に、どんな走行条件で、どんな信号をトリガーにして、どんな現象を収録し判断につなげるのか、試験条件を満たす走行パターンで車両生産スケジュールに影響を与えないのか、安全は確保出来ているかなど、何度も何度もトライ&エラーを繰り返し、走行条件を見つけることができた。さらに、出来上がった走行条件を検査員(車両工場ドライバー)が安定走行できるまで、徹底的に模擬走行教育・訓練を繰り返し、関係者が一致団結し課題を乗り越え、無事に活動を遂行できた。

まさに、開発で作りに上げた魅力品質が数千、数万と生産される車両でも確保されているか、現物(現車)を現場(工場)で現象(データ)を用いて確認した活動である。

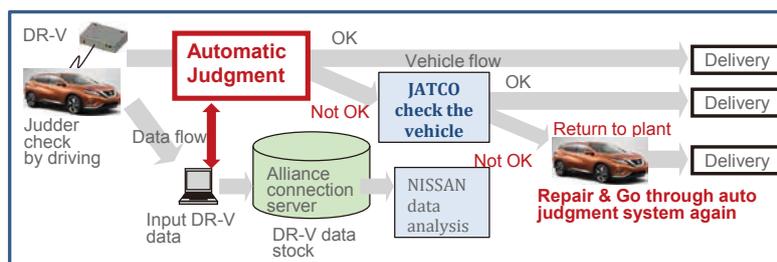


Fig. 2 Flow of DR-V activity

#### 4. CVT7 W/R TASK活動について (新機種投入に対する品質管理)

市場品質向上のため、Fig.3に示す自動車メーカーと一体なったTASK活動を実施中である。このTASK活動とは、我々の製品がお客様の要求ニーズに応えられているかを確認する活動であり、以下の目的を達成すべく活動を実施した。

- お客様の要求情報を迅速かつ的確に認識し、責任部署にフィードバックし早期品質向上につなげること。
- 速やかに効果的な品質向上を織込み、お客様満足につなげること。

これらの目的を達成するためには、市場情報を正しく、素早く共有化し、迅速かつ的確な対策活動を行うことが重要である。そこで、社内の関係部門は勿論、自動車メーカーともデイリーで情報を取り交わし、新規入電情報や課題解決中の案件に対する進捗フォローをきめ細かく実施し、必要に応じてお客様の車両を調査して発生している事象を現場、現物で確認することを徹底して実行した。

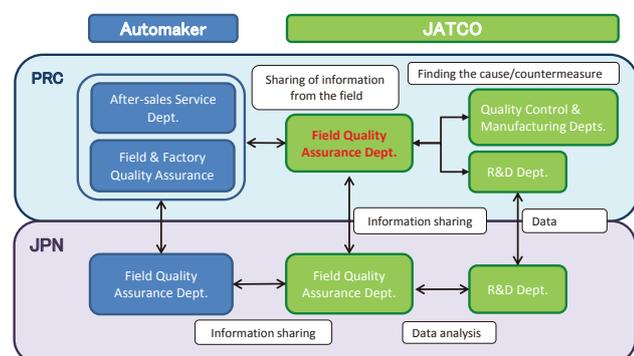


Fig. 3 Organization for TASK activities

#### 5. まとめ

海外プロジェクトの品質向上活動を実施した結果、懸案情報入手に要していた時間は従来に比べ1/3に短縮、また現品回収についても1/2に短縮することが出来、市場品質へのフィードバックする時間を飛躍的に短縮することができた。

品質向上活動は必要不可欠の活動であり、今後も継続して改善活動に取り組んでいきたい。

#### 4. TASK Activities for New CVT7 W/R: Quality Control for New Model Launch

The TASK activities shown in Fig. 3 are carried out jointly with the automakers to improve product quality in the field. These activities confirm whether our products fully respond to customers' needs and wants. Activities for the new CVT7 W/R were carried out to achieve the following objectives.

- To comprehend quickly and accurately the information that customers want and to feed it back to the responsible department so that it leads to early improvement of quality.
- To deploy effective measures for improving quality quickly that lead to better customer satisfaction.

In order to accomplish these objectives, it is essential to gather accurate information on products in the field, share it promptly and initiate suitable countermeasure activities immediately. Toward that end, naturally the related departments at JATCO and also the automakers exchanged information daily. The progress of issues being worked on was monitored closely along with any newly obtained information. If necessary, a customer's car was examined so that the problem being experienced could be thoroughly investigated and confirmed by actually driving the vehicle under real-world conditions.

#### 5. Conclusion

As a result of carrying out these activities to improve quality in this overseas project, the time needed to obtain information about issues of concern was shortened to one-third of that required previously, and the time needed to collect the parts involved was also cut in half. As a result, the time needed for feedback and response to quality issues in the field was dramatically shortened.

Such activities for improving quality are absolutely indispensable. We intend to continue our efforts to promote quality improvement activities in the future.

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# Jatco CVT7 W/Rの新バリエータ開発

Development of New variator system for the Jatco CVT7 W/R

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**抄 録** ジヤトコは2009年に世界初の副変速機付きCVT(以下Jatco CVT7)を発表した。そのJatco CVT7は小型で燃費競争力が高く、小型車、軽自動車で広く使用されており、すでに800万台を市場投入した。今回このJatco CVT7をベースに、小型であるパッケージを損なうことなく、ドライバビリティを向上させるとともに、Ratio coverage(以下 R/C)の拡大とフリクション低減アイテムの採用による燃費性能向上を実現した。

本論文では、そのワイドレンジ型CVT7であるJatco CVT7 W/R(以下 CVT7 W/R)に織り込んだバリエータシステム技術について記述する。

**Summary** In 2009, JATCO released the Jatco CVT7, the world's first CVT to feature an auxiliary gearbox. Thanks to its compact size and high fuel economy competitiveness, the Jatco CVT7 has been widely used on minivehicles and small cars. Eight million units of this CVT have already been put on the market. Developed on the basis of the Jatco CVT7, the Jatco CVT7 W/R improves driveability, expands the ratio coverage, and enhances fuel economy through the adoption of various measures for reducing friction, without sacrificing compact packaging. This article describes the technical features of the new variator system incorporated into the Jatco CVT7 W/R, the wide range version of the Jatco CVT7.

## 1. はじめに

Jatco CVT7をベースに、多様な市場ニーズに適合する小型CVTを開発すべく、以下をコンセプトとしてCVT7 W/Rを開発した。新開発ユニットのコンセプトを実現するためにCVTバリエータシステム技術としてはTable 1に示す課題に取り組んだ。Fig.1に新開発したベルトのエレメント形状を示す。

Table 1 Features of Newly developed variator

Target		Measures
Fuel efficiency improvement	$\mu$ improvement for reducing oil pump friction	New flank geometry for High friction coefficient High stiffness pulley
	Mechanical loss reduction	Smaller Rocking edge height Smaller end play
	Flexibility optimization	Smaller belt running radius for extending high ratio

## 1. Introduction

Based on the Jatco CVT7, the Jatco CVT7 W/R was developed around the concept explained below so as to achieve a compact CVT capable of meeting diverse market needs. Table 1 outlines the technical measures that were adopted to address various issues in the process of developing a new CVT variator system for accomplishing the target set for the new CVT7 W/R.

The element geometry of the newly developed belt is shown in Fig. 1 in comparison with that of the previous belt.



Fig. 1 Newly developed 24-mm belt

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## 2. バリエータ開発の狙い

今回CVT7 W/Rに搭載されたバリエータは、ユニットコンセプトに基づき燃費性能向上を狙い、新開発を行った。

特筆すべき特徴は、燃費向上のためにエレメントの形状変更に取り組んだことである。また、プーリの剛性を最適化することにより、容量とR/Cの拡大を両立することが可能となった。また、ベルトの開発においては開発パートナーのBosch Transmission Technology B.V.(以下Bosch社)と共同開発を行った。

## 3. 燃費向上技術開発の紹介

Table 1に示す5項目の具体的な改善アイテムを紹介する。

### 3.1. バリエータ $\mu$ 向上技術

効率向上の取り組みとして、オイルポンプ(以下O/P)フリクション低減を目的に、ベルト-プーリ間の $\mu$ を向上し、ベルトを挟み込むプーリ推力の低減に取り組んだ。

#### 3.1.1. 新フランク溝形状の開発

O/Pの駆動損失を低減するためには、プーリ推力低減が有効である。実現するためにはエレメント-プーリ間の $\mu$ 向上が必要となる。 $\mu$ 向上のアプローチとして、エレメントフランク部の形状パラメータを用いて実験計画法による基礎実験を行った。その結果、 $\mu$ を向上させる有効なパラメータとして、フランクの山ピッチ間隔とフラット部面積にあることを確認した。山ピッチは油の排出性を良くし、フラット部面積は接触面積向上に寄与する。Fig.2へ形状の定義を示す。

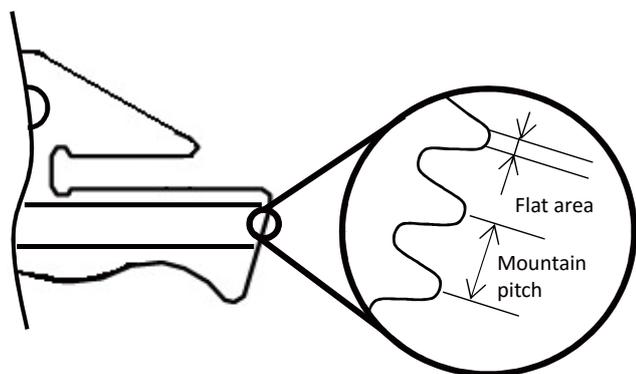


Fig. 2 Definition of flank geometry

## 2. Development Aims for the New Variator System

A new variator system was developed with the aim of further improving fuel economy in line with the development concept defined for the new CVT7 W/R. One notable feature is that the geometry of the belt elements was changed for the purpose of enhancing fuel economy. Another significant feature is that optimization of the pulley stiffness made it possible to increase both the torque capacity and ratio coverage. A new belt was jointly developed with Bosch Transmission Technology B.V. (Bosch), our partner in this belt development project.

## 3. Introduction of Technical Measures Developed for Improving Fuel Economy

This section describes the specific details of the five improvement measures listed in Table 1.

### 3.1 Improvement of variator friction coefficient

Oil pump friction was reduced as one means of improving efficiency. Toward that end, the friction coefficient ( $\mu$ ) between the belt and pulleys was increased and pulley thrust for clamping the belt was reduced.

#### 3.1.1 Development of new flank groove geometry

Reducing pulley thrust for clamping the belt is effective in reducing oil pump drive loss. To accomplish that, it is necessary to improve the friction coefficient between the belt elements and the pulleys. As one approach to improving the friction coefficient, fundamental tests were conducted under the design of experiments method using the element flank geometry as the parameter. The results revealed that the groove ridge pitch and flat area of the ridges were effective parameters for improving the friction coefficient. It was confirmed that the ridge pitch improves oil evacuation performance and that the flat area contributes to increasing the area of contact with the pulleys. Figure 2 illustrates the definition of the new flank geometry.

Fig.3にはフランク形状の成立するエリアを示す。X軸を山ピッチとして、Y軸はフラット部エリアとした。成立エリアは油の排出性よりNGとなるエリアと幾何学的に形状が成立するエリアで示している。

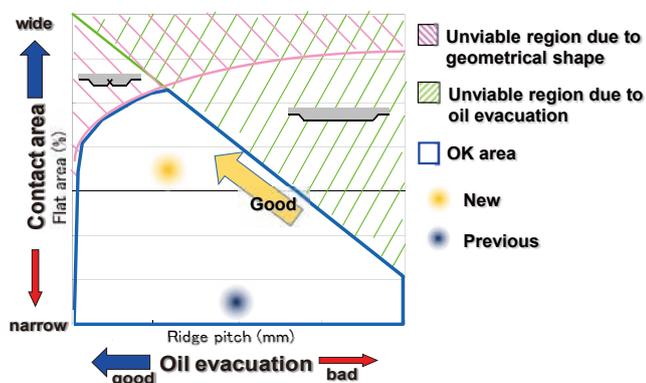


Fig. 3 Redesigned ridge pitch and flat area

新形状は油の排出性を良好にすることを目的として山ピッチを30%減少させた。また、接触面積を拡大させるために山形状を最適化して80%増加させた。新開発したエレメントフランク部の形状比較をFig.4に示す。

その結果、新形状とすることで5%の $\mu$ 向上をトライボテストにより確認した。

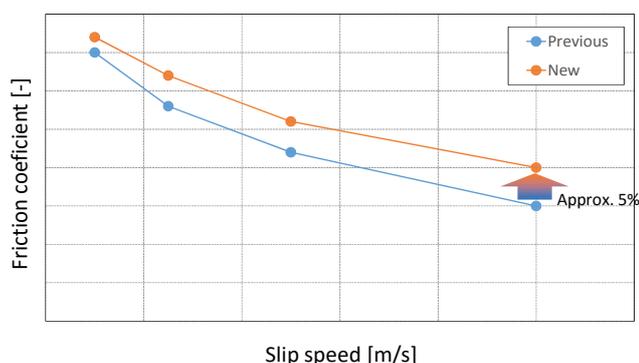


Fig. 5 Improvement of friction coefficient

### 3.1.2. プーリ剛性最適化

プーリは油圧を受けて弾性変形が生じる。弾性変形を受けると、エレメント-プーリの接触面積が減少し、 $\mu$ 低下の要因となる。そのため、本開発ではプーリの変形を低減させることに着目した。新形状ではプーリの剛性を約30%向上させ、5%の $\mu$ 向上を実現した。プーリによる $\mu$ 向上効果をFig.6に示す。

Figure 3 shows the region of the viable flank geometry in terms of the ridge pitch on the horizontal axis and the flat contact area on the vertical axis. The viable region lies between the area that is unacceptable due to poor oil evacuation and the area that is unacceptable due to the geometrical shape.

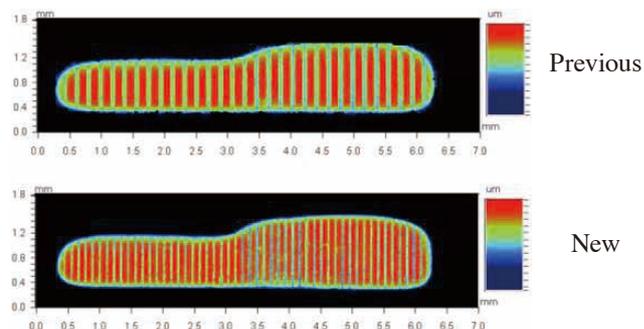


Fig. 4 Comparison of element flank geometry

The new geometry reduces the ridge pitch by 30% for the purpose of obtaining good oil evacuation. The top flat area of the ridges was optimized and increased by 80% for the purpose of expanding the area of contact with the pulleys. The newly developed element flank geometry is compared in Fig. 4 with the previous geometry. The results of a tribological test confirmed that this new flank geometry improved the friction coefficient by 5%.

### 3.1.2 Optimization of pulley stiffness

The application of hydraulic pressure causes the pulleys to undergo elastic deformation, which reduces the area of contact with the belt elements, thereby causing the friction coefficient to decline. Therefore, one focus of the development work was to reduce pulley deformation. The new geometry increased the pulley stiffness by approximately 30%, which improved the friction coefficient by 5%. The effect of the pulley stiffness on improving the friction coefficient is shown in Fig. 6.

The combined effect of these two measures worked to improve the torque capacity by 10%. Figure 7 compares the measured torque capacity of the new unit and the previous unit.

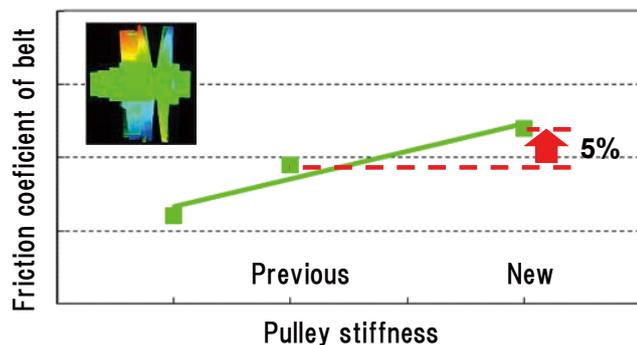


Fig. 6 Pulley stiffness improvement

これらの2つのアイテムの組み合わせにて10%のトルク容量増加を得ることができた。Fig.7へトルク容量を測定した結果を示す。

### 3.2. メカロス低減技術

ユニットのメカロス低減を目的としてベルト内部フリクションの低減を行った。

#### 3.2.1. エlement-リング間相対滑り低減

ベルトはエレメントとリングの2要素で構成されており、運転中はリング-リング間、エレメント-リング間で回転半径差による相対滑りが発生している。この後者の相対滑りはエレメントがプリー巻き付き部でリングの回転半径と異なる位置(このエレメント部位をロッキングエッジ高さと呼ぶ)にてトルク伝達を行うために発生するものである。今回内部フリクションを低減させる方策として、リング-エレメント間の相対滑りに着目した。このロッキングエッジ高さを新ベルトでは20%減少させることで相対滑り量の低減を図った。Fig.8は回転半径低減を示した図である。

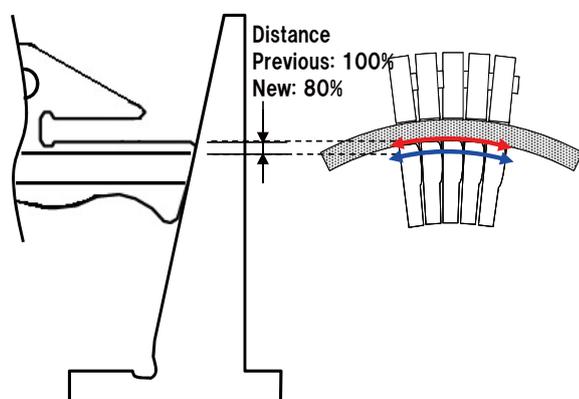


Fig. 8 Element geometry optimization

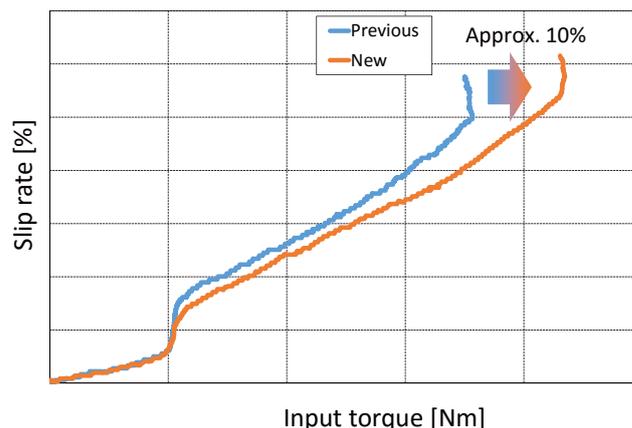


Fig. 7 Improvement of torque capacity

### 3.2 Technical measure for reducing mechanical losses

Internal friction of the belt was reduced for the purpose of reducing the mechanical losses of the CVT7 W/R.

#### 3.2.1 Reduction of relative slipping between belt elements and rings

The belt is composed of two constituent parts: elements and rings. During operation, relative slipping occurs between the rings and between the belt elements and the rings owing to differences in their radius of rotation. The latter relative slipping is caused by the transmission of torque at the place where the radius of rotation of the rings differs in the area where the belt elements are wrapped around the pulleys. (That part of the belt elements is referred to here as the locking edge height.) In this development project, attention was focused on the relative slipping between the belt elements and the rings as a means of reducing internal friction. The amount of relative slipping was reduced by reducing the locking edge height of the new belt elements by 20%.

The reduced radius of rotation is compared with the previous distance in Fig. 8.

### 3.2.2. エlement間隙 (end play) 詰め

トルクを伝達する際にFig.9に示すようなエレメント-エレメント間の隙間が生じる。その要因は、リングが推力を受けて弾性変形による伸びが発生することと、エレメントがトルク伝達の圧縮力により圧縮されることにある。この隙間はエレメントがトルク伝達部と非トルク伝達部を繰り返し通過する際に、この隙間を詰める仕事をするため、ベルトの効率を低下させている。このエレメント初期隙間を50%詰めることで0.3%の効率向上を実現した。

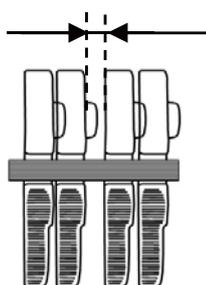


Fig. 9 Element gap (end play)

### 3.3. R/C拡大

Jatco CVT7は副変速機を使用し、2段階に切り替えることによってR/Cの拡大を行っている。CVT7 W/Rではさらに、最HighレシオをさらにHigh側へ拡張を行った。

体格変更なしにR/C拡大を行うと、ベルトの巻き付き半径を小径化することとなり、ベルトのリングには従来よりも大きな曲げ応力が発生することとなる。新ベルトでは約4倍の寿命向上を実現した新リング材を使用することで、体格を変更することなく最Highレシオを0.55から0.459へ拡大が可能となった。R/C拡大のイメージをFig.10へ示す。

### 3.2.2 Reduction of gaps between elements (end play)

As illustrated in Fig. 9, tiny gaps occur between the belt elements in the process of transmitting torque. One cause of such gaps is the stretching of the rings due to their elastic deformation when thrust is applied to them. Another cause is compression of the elements due to the compressive force involved in transmitting torque. The elements work to close the gaps as they repeatedly pass through the torque-transmitting and non-transmitting regions, resulting in a reduction of belt efficiency. Reducing the initial element gap by 50% improved belt efficiency by 0.3%.

### 3.3 Expansion of ratio coverage

The Jatco CVT7 expands the ratio coverage by using the auxiliary gearbox to switch between two ratio levels. For the CVT7 W/R, the maximum High ratio was further expanded on the High side.

Simply expanding the ratio coverage without changing the size of the unit would reduce the running radius of the belt on the pulleys. As a result, that would induce larger bending stress in the rings than before. The rings of the new belt are made of a new material that improves their service life by approximately fourfold. That made it possible to expand the maximum High ratio from 0.55 to 0.459 without changing the size of the unit. The concept for expanding the ratio coverage is outlined in Fig. 10.

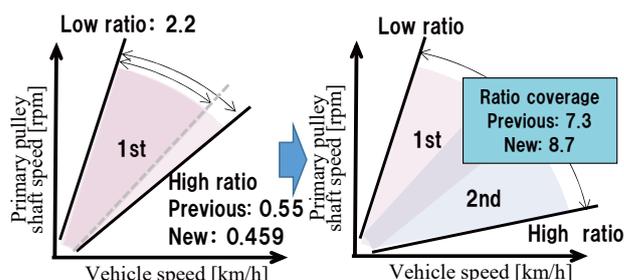


Fig. 10 Ratio coverage expansion obtained with the new belt

#### 4. まとめ

Jatco CVT7 W/Rは、当社として企画から開発まで行った新型24mmベルトを採用した。この新型ベルトはCVT7 W/Rのトランスミッション効率として5%の向上に貢献し低燃費(高効率化)、動力性能向上、小型化に大きく貢献できた。

本開発に際して多大なる協力をいただいたBosch社および、関係者の皆様に深く感謝の意を表す。

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- 2) Masahiro kusuda, Development of a New Steel Belt for the Jatco CVT8, The 7th Symposium China-ICE, HEV and EV Transmissions and Drives, 24/04/2015, P.260

#### 4. Conclusion

The Jatco CVT7 W/R features a new 24-mm belt that Jatco was responsible for planning and developing. This new belt contributes to a 5% improvement in the transmission efficiency of the CVT7 W/R. It also contributed significantly to the downsizing of the unit and helps to improve fuel economy and driveability.

The authors would like to thank Bosch and everyone concerned for their invaluable cooperation with the development of the new variator system.

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■ Authors ■



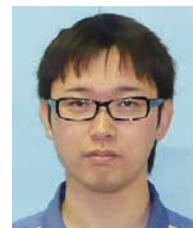
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# Jatco CVT7 W/R 高効率油圧システムの開発

Development of a High-efficiency Hydraulic System for the Jatco CVT7 W/R

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**抄 録** 地球環境保護などのニーズにより、自動車に対する燃費改善要求が高まっている。Jatco CVT7 W/R (以下、CVT7 W/R)では、さらなる燃費改善と、運転性向上という、相反する性能の両立を目指した。

本稿では、CVT7 W/Rにおけるフリクション低減と、運転性向上を目的とした高効率油圧システム開発の取り組み内容について紹介する。

**Summary** There have been growing demands to improve vehicle fuel economy in order to protect the global environment, among other needs. The aim set for the Jatco CVT7 W/R (Wide Range) was to achieve both a further improvement in fuel economy and enhanced driveability, which are conflicting performance attributes. This article describes the measures taken to develop a high-efficiency hydraulic system that was designed to reduce friction in the CVT7 W/R and improve driveability.

## 1. はじめに

ベルトCVTは、径の大きなプリーピストンを作動させることで変速を実現する構造であるため、大流量と高いベルトクランプ圧力が必要となる。従って、オイルポンプを始めとする油圧システムの仕事量が大きく、油圧システムの効率向上が、燃費改善のために重要となる。本稿では、CVT7 W/Rの油圧システム開発の狙い、概要、取り組み課題について述べる。

## 2. 開発の狙い

(1) プリー圧減圧弁の追加により、プリー圧を最適設定することで伝達効率の向上を狙った。

- ・追加部品の最適なレイアウトによる、従来コントロールバルブからの変更による影響を最小化
- ・油圧安定性、応答性を満足する、プリー圧減圧弁仕様の決定

これにより、プリー圧を最適設定することで従来CVTに対して伝達効率の3%向上に寄与した。

(2) オイルポンプ流量制御弁の廃止によるオイルポンプフリクションの低減。(ポンプ内部圧力損失の低減)

- ・コントロールバルブへの流入流量増加に対する技術課題の対応(耐摩耗性向上, 圧力損失改善)

## 1. Introduction

A steel-belt CVT is constructed such that ratio changes are accomplished by actuating large-diameter pulley pistons, which requires a large fluid flow rate and high belt clamping pressure. That means the hydraulic system, and the oil pump in particular, must do a lot of work. Therefore, improving the efficiency of the hydraulic system is vitally important for improving fuel economy.

This article describes the development aims set for the hydraulic system of the CVT7 W/R, presents an overview of the system, and explains the issues that were addressed in the development work.

## 2. Development Aims

(1) One aim was to improve transmission efficiency by adding a pulley pressure regulator valve for setting the optimal pulley pressure.

The layout of the added parts was optimized to minimize any effect of the changes on the existing control valve. The specifications of the pulley pressure regulator valve were determined so as to obtain satisfactory pressure stability and responsiveness.

These measures make it possible to set the optimal pulley pressure, thereby improving transmission efficiency by 3% over the existing base model.

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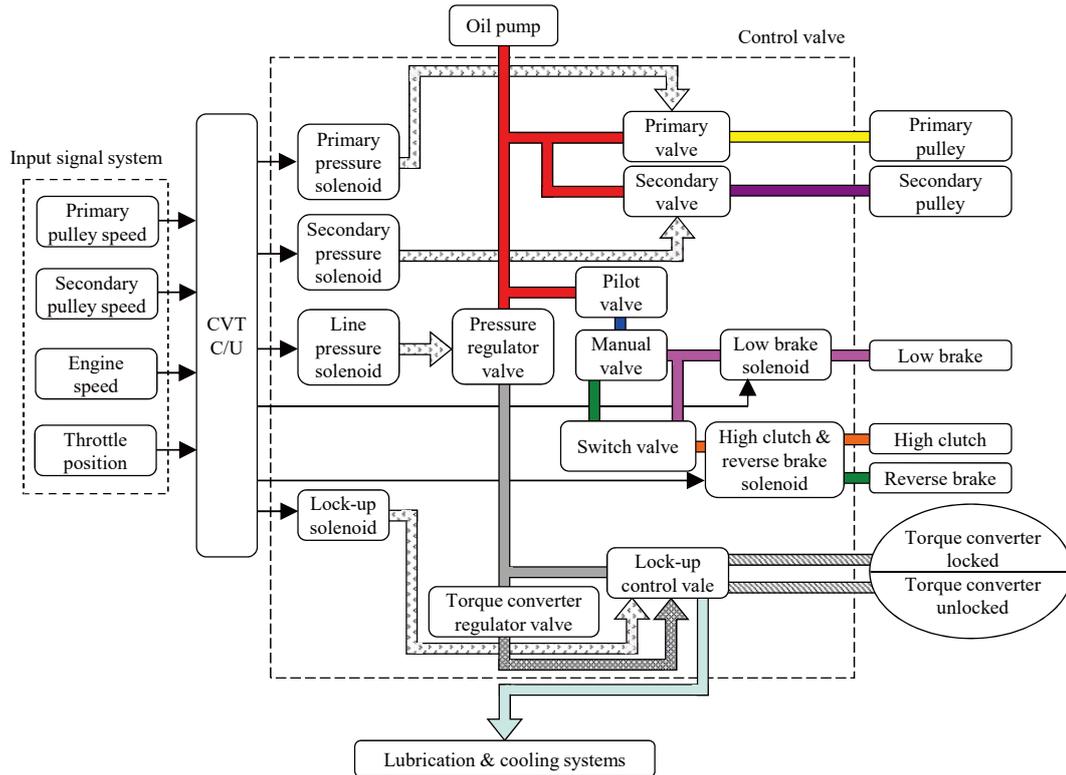


Fig. 1 Hydraulic system

### 3. 油圧システム概要

油圧制御回路の全体構成は、弊社の従来CVT7と同様に、使用油圧の高いプリー圧系を上流、トルクコンバータ圧系を下流とした階層配置とした (Fig.1).

CVT7 W/Rでは、従来の油圧回路構成に対して、セカンダリプリー圧をライン圧に対して減圧するための大容量三方リニアソレノイドおよび、セカンダリプリー圧減圧弁を追加する構成とした (Fig.2).

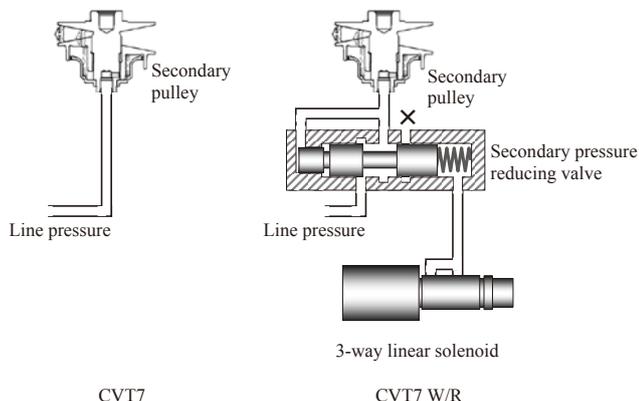


Fig. 2 Hydraulic circuit for secondary pulley

(2) A second aim was to reduce oil pump friction, i.e., pressure losses inside the pump, by discontinuing the flow control valve of the oil pump.

This change would increase the flow rate into the control valve, causing technical issues that had to be addressed, including improving anti-wear performance and reducing pressure losses.

### 3. Overview of Hydraulic System

The overall configuration of the hydraulic control circuit has a hierarchical layout in which the pulley pressure system that requires high hydraulic pressure is positioned upstream and the torque converter pressure system is located downstream. This hierarchical structure is the same as that of the existing Jatco CVT7 (Fig. 1).

In comparison with the existing hydraulic circuit configuration, the system for the CVT7 W/R is configured with an additional large-capacity three-way linear solenoid and a secondary pulley pressure regulator valve to reduce the secondary pulley pressure relative to the line pressure (Fig. 2).

#### 4. 取り組み課題

#### 4. Issues to be Addressed

##### 4.1. プーリ圧減圧弁の追加による課題

##### 4.1 Issue due to addition of pulley pressure regulator valve

##### 4.1.1. コントロールバルブレイアウトの最適化

##### 4.1.1 Optimization of control valve layout

セカンダリプーリ圧をライン圧に対して減圧するための部品を追加するにあたり、CVT7 W/Rでは、従来CVT7に対して生産設備への影響を最小限にするために、取り付け相手部品であるトランスミッションケースの加工設備改造が不要となるように、具体的には、各油圧回路の受け渡し位置やボルト位置を変更することなく、各スプール弁およびソレノイドバルブのレイアウトを最適化した(Fig.3).

In connection with the addition of parts for reducing the secondary pulley pressure relative to the line pressure, it was necessary to minimize any impact of these hydraulic system changes on the production facilities for the existing CVT7. Specifically, the layout of each spool valve and solenoid valve was optimized so that the pressure transfer positions in the hydraulic circuit and the bolt positions were not changed (Fig. 3). That made it unnecessary to modify the machining facilities of the transmission case to which the parts added to the CVT7 W/R hydraulic system are attached.

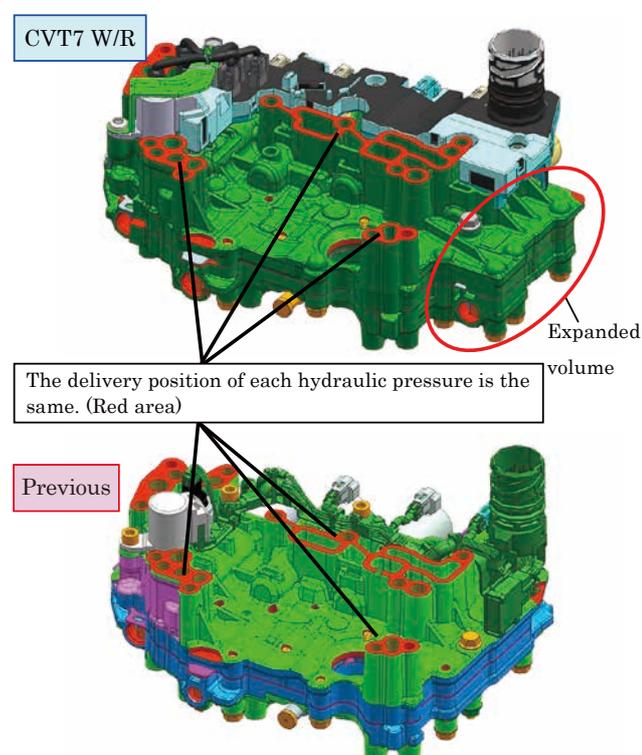


Fig. 3 Control valve assembly

##### 4.1.2. 油圧安定性、応答性の確保

##### 4.1.2 Assurance of pressure stability and responsiveness

油圧安定性と、応答性を両立するプーリ圧減圧弁の仕様を検討するにあたり、油圧シミュレーションモデルに、3次元流体解析による回路圧損計算結果、および、スプールのノッチ等の複雑な形状まで考慮したモデルを織り込むことにより予測精度の向上に取り組んだ。

Measures were taken to improve the prediction accuracy of the pressure simulation model in order to study the specifications of the pulley pressure regulator valve for the purpose of achieving both pressure stability and responsiveness. In this regard, the hydraulic circuit pressure loss calculated with a 3D computational fluid dynamics (CFD) simulation was incorporated into the model along with a model for taking into account various complex geometries, including spool valve notches.

これにより、これまで予測が困難であった油圧の過渡的な安定性や応答性を、シミュレーションにより検討可能となり、最適な設計仕様を決定することができた(Fig.4).

These improvements made it possible to examine the transient pressure stability and responsiveness by simulation, which have been very difficult to predict in the past. As a result, that made it possible to determine the optimum design specifications (Fig. 4).

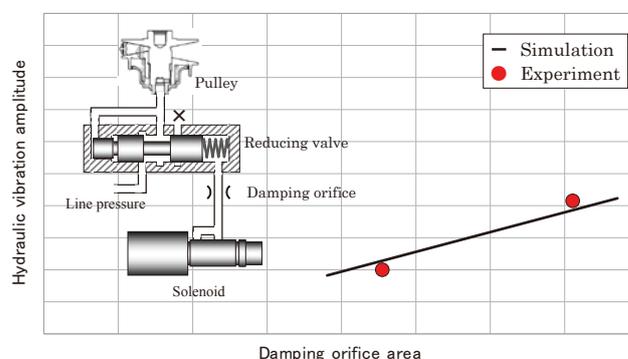


Fig. 4 Results for hydraulic pressure vibration amplitude

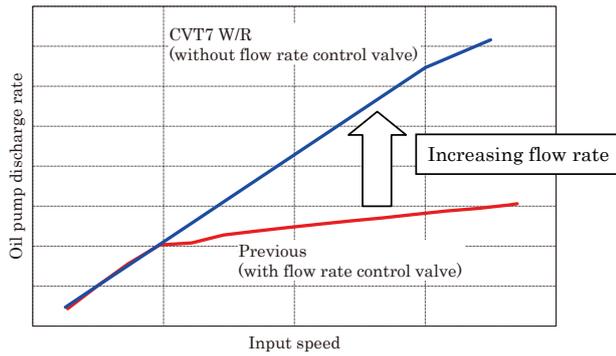


Fig. 5 Oil pump discharge rate per revolution

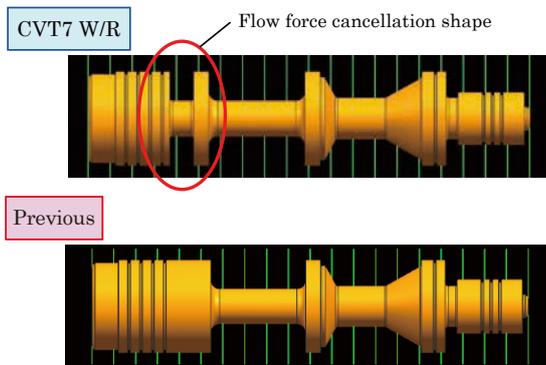


Fig. 6 Comparison of pressure regulator valve shapes

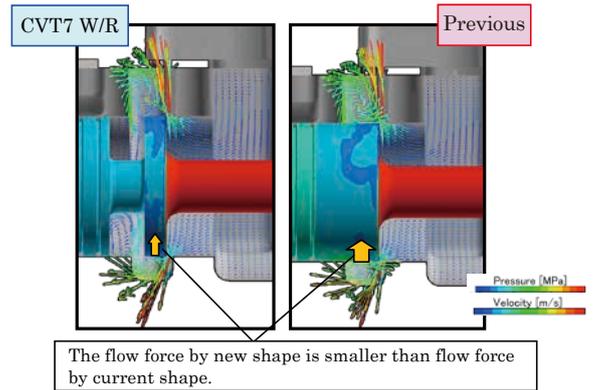


Fig. 7 Results of 3D flow simulation

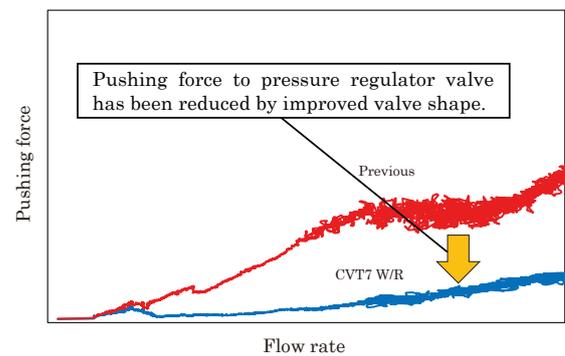


Fig. 8 Pushing force of pressure regulator valve

## 4.2. オイルポンプ流量制御弁の廃止による課題

### 4.2.1. コントロールバルブ耐摩耗性向上技術

オイルポンプの流量制御弁廃止に伴い、コントロールバルブへの流入流量が増加する(Fig.5)ことで、スプールの押付け力増加によるバルブボディの耐摩耗性が課題となる。

CVT7 W/Rでは、プレッシャレギュレータバルブの押付け力低減形状を流体解析を用いて決定した(Fig.6, 7)。これにより、大流量の入力でも、十分な耐久性を確保することが可能となった(Fig.8)。

### 4.2.2. 大流量に対応した油圧回路形状の最適設計

コントロールバルブへのオイルポンプからの流入流量が増加するため、コントロールバルブ本体内部の油路における圧力損失が増加することが懸念される。

そこで、回路全体に3次元流体解析を用いることで、大流量に対応した最適なコントロールバルブボディを設計することができた(Fig.9)。

## 4.2 Issue due to discontinuation of the oil pump flow control valve

### 4.2.1 Approach for improving control valve anti-wear performance

Discontinuing the flow control valve of the oil pump would increase the flow rate into the control valve as shown in Fig. 5. As a result, that would increase the pushing force of the spool, making the anti-wear performance of the valve body an issue of concern.

For the CVT7 W/R, the shape of the pressure regulator valve was determined by CFD simulations so as to reduce the pushing force (Figs. 6 and 7). That made it possible to ensure ample valve body durability even against the force produced by high flow rates (Fig. 8).

### 4.2.2 Optimum design of hydraulic circuit geometry for handling high flow rates

There was concern that pressure losses in the flow passage inside the control valve would increase owing to the higher flow rate into the valve from the oil pump.

To address this issue, a 3D flow simulation was conducted of the entire hydraulic circuit, making it possible to design the optimum control valve body capable of handling high flow rates (Fig. 9).

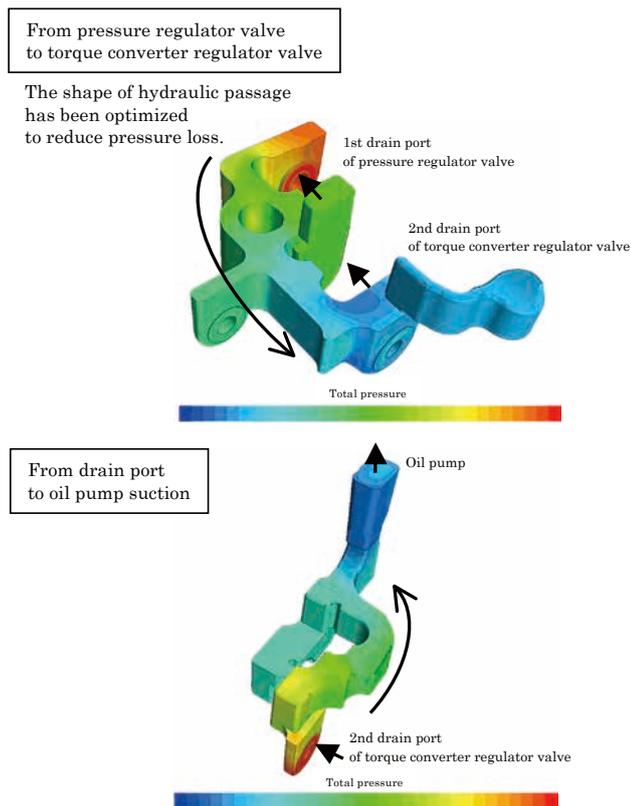


Fig. 9 Pressure loss

## 5. おわりに

CVT7 W/Rの開発において、3次元モデルでの詳細流体解析と、油圧シミュレーションによるパラメータ検討を行うことで、最適な仕様設計が可能となり、その結果、CVTの競争力向上のための高効率油圧システムを実現することができた。

今後もCVT7 W/Rの開発で培ったシミュレーションの精度の向上などにより、さらなるCVTの効率改善に取り組んでいきたい。本システムの開発に当たり、多大なるご協力をいただいた、社内外の方々に厚く感謝申し上げます。

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## 5. Conclusion

In the process of developing the CVT7 W/R, parametric studies were conducted by performing detailed pressure simulations with a 3D CFD model, which resulted in the optimal design specifications. Consequently, that made it possible to achieve a high-efficiency hydraulic system for improving the competitiveness of this CVT.

We plan to continue to improve CVT efficiency further in the future by utilizing the improved simulation accuracy and other improvements accumulated in the course of developing the CVT7 W/R. We would like to express our deep appreciation to everyone inside and outside the company who contributed significantly to the development of this hydraulic system.

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# 流量制御弁レスオイルポンプの開発によるオイルポンプ駆動トルクの低減

Reduction of Oil Pump Drive Torque by Developing a Pump without a Flow Control Valve

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**抄 録** 新世代新型Jatco CVT7 W/R(以下 CVT7 W/R)では、近年の燃費改善に対する市場のニーズに答えるために、オイルポンプのフリクション低減を目的として流量制御弁レスオイルポンプを採用した。

本稿ではその取り組みについて紹介する。

**Summary** An oil pump without a flow control valve was developed and adopted for the new-generation Jatco CVT7 W/R with the aim of reducing pump friction in order to meet recent market needs for improved fuel economy. This article describes the development of this oil pump.

## 1. はじめに

従来のCVT用オイルポンプでは、流量制御弁により吐出路から吸入路へと高圧のオイルを一部リターンさせ、吸入路中のエア析出を防止することで油中に高濃度のエアが混入した状態においても十分な吐出流量を確保していた。

本開発では流量制御弁を廃止することにより、流量制御弁を作動させるためのオリフィスの通過抵抗や流量制御弁で発生する環状リークを解消することを課題とし、さらなる燃費向上を目指した。

## 2. オイルポンプの構造および特徴

### 2.1. 主要諸元

Table 1にJatco CVT7(以下 CVT7)およびCVT7 W/Rのオイルポンプ主要諸元を示す。

Table 1 Major specifications of pumps

	CVT7 W/R	CVT7
Installation configuration	External	External
Speed increase ratio	1.088	1.088/1.029
Basic displacement (cc/rev)	11.4	13.1/12.3
Oil pump type	Vane	Vane
Weight (g)	950	1050

## 1. Introduction

Oil pumps for CVTs have traditionally used a flow control valve to return a portion of the fluid under high pressure from the discharge passage to the suction passage. This prevents air entrainment in the suction passage and ensures an ample discharge flow rate even under a condition where a high concentration of air is mixed in the fluid.

The oil pump described here was developed without a flow control valve for the purpose of further improving vehicle fuel economy. This was accomplished by eliminating the flow resistance through the orifice for activating the flow control valve and the annular leakage that occurs at the flow control valve.

## 2. Oil Pump Structure and Features

### 2.1 Major specifications

Table 1 lists the major specifications of the oil pumps used with the Jatco CVT7 and the CVT7 W/R.

### 2.2 Oil pump features

The schematic diagrams in Fig. 1 compare the flow passage configuration inside the two pumps. The oil pump of the CVT7 W/R is built such that all the discharged fluid is sent to the control valve and the unnecessary portion is returned to the pump. This differs from the conventional structure where the fluid is returned from the flow control valve. Consequently, the orifice previously provided for activating the flow control valve was discontinued,

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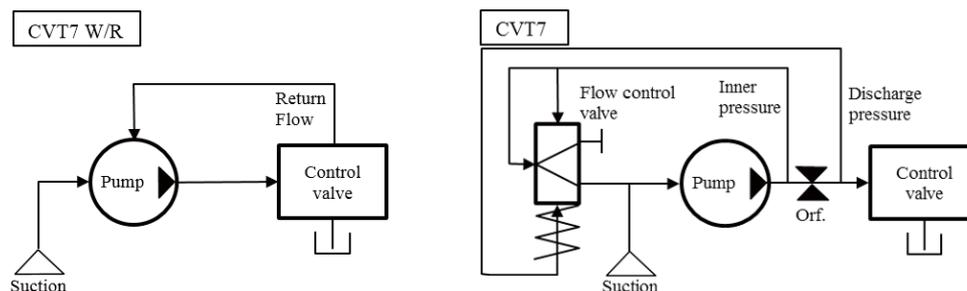


Fig. 1 Oil flow in pump

## 2.2. オイルポンプの特徴

Fig.1にポンプ内油路構成を示す. CVT7 W/Rではオイルポンプから吐出されたオイルを全てコントロールバルブへと送り, 不要分をポンプへとリターンさせる構造としており, 従来の流量制御弁よりオイルをリターンさせる構造から変更している. これにより流量制御弁を作動させるために設けていたオリフィスを廃止し, 次の式で定義される損失Pを無くすことが可能となった.

$$P = \frac{\rho}{2} \times \left[ \frac{Q \times 10^{-3}}{60} \times \frac{1}{c} \times \frac{1}{A \times 10^{-6}} \right] \times 10^{-6} \quad (1)$$

ここで $\rho$ はオイル密度,  $Q$ は流量,  $c$ は流量係数,  $A$ はオリフィス径である.

また, 流量制御弁よりリークする流量を無くすことにより, 固有吐出量 $V_{th}$ を小さくすることが可能となる. それによって次式で定義されるポンプ駆動のためのトルク $TQ$ を減らすことが実現でき, ENG負荷を減らして燃費向上が図れた.

$$TQ = \frac{V_{th} \times P}{2\pi} \quad (2)$$

Fig.2およびFig.3へとENG回転数に対する吐出流量および駆動トルクの特徴を示す.

これら流量制御弁の廃止およびオイルポンプ固有吐出量小型最適化により, 実吐出量の低下を伴わずに30%以上のフリクション低減に成功した.

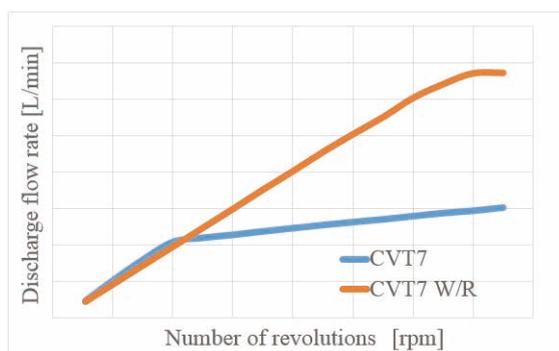


Fig. 2 Flow rate of oil pump

making it possible to eliminate the loss  $P$  defined in the following equation.

$$P = \frac{\rho}{2} \times \left[ \frac{Q \times 10^{-3}}{60} \times \frac{1}{c} \times \frac{1}{A \times 10^{-6}} \right] \times 10^{-6} \quad (1)$$

where  $\rho$  denotes the oil density,  $Q$  the flow rate,  $c$  the flow coefficient and  $A$  the orifice diameter.

Additionally, because fluid leakage from the flow control valve is eliminated, the intrinsic discharge flow rate  $V_{th}$  of the oil pump can be reduced. This allows the torque  $TQ$  for driving the pump, as defined in the following equation, to be reduced, which has the effect of lowering the engine load and improving fuel economy.

$$TQ = \frac{V_{th} \times P}{2\pi} \quad (2)$$

The discharge flow rate of the oil pumps and their drive torque are shown as a function of the engine speed in Figs. 2 and 3, respectively. The discontinuation of the flow control valve and optimization of the intrinsic discharge flow rate of the oil pump effectively reduced friction by 30% without any decrease in the actual discharge flow rate.

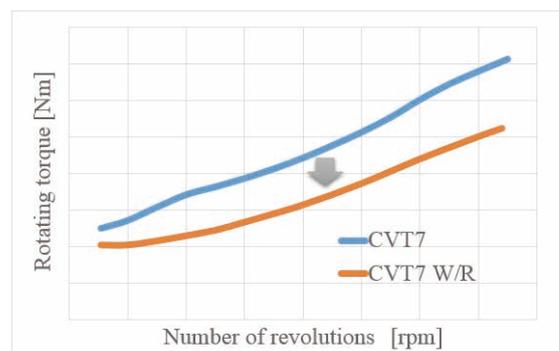


Fig. 3 Rotating torque of oil pump

### 3. 技術課題とその対応

### 3. Technical Issues and Solutions

流量制御弁を廃止することにより発生する課題として、オイル中にエアが多く含まれた状態での脈動やノイズが挙げられる。

CVT7 W/Rでは下記アプローチを行うことにより本課題を解決した。

- ・吸入油路拡大によるエア析出防止
  - ・低圧室から高圧室への油圧立ち上がり最適化
  - ・ユニット内部流れ最適化によるエア含有率低減
- 詳細を以下に記す。

#### 3.1. 吸入油路拡大によるエア析出防止

従来の当社CVT用ベーンポンプでは流量制御弁のリターン圧を最適化する吸入路形状としていたが、CVT7 W/Rではエアの析出を抑える形状に最適化した。

Fig.4に吸入路内での圧力分布解析結果を示す。従来の吸入路形状では流量制御弁のリターン圧が加わらない状態では圧力分布にむらがあり、局所的な低圧部にてエアが析出する形状となっていた。

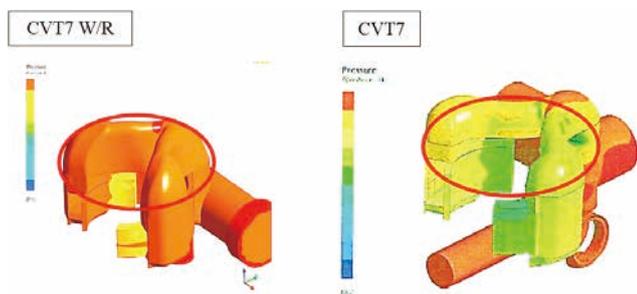


Fig. 4 Pressure distribution at inlet port of oil pump

本形状の課題として、ベーン室に入る直前の通路が狭く、エアの析出を誘発してしまうため、解決策としてFig.5にあるような切欠きをベーン摺動面に入れた。

切欠きを入れることでベーン室直前の通路を拡大することが出来るが、ベーンの摺動部面積が狭くなり面圧が高くなってしまったため、吸入路面積と部品耐力の限界を見極め、形状最適化を行った。

Examples of issues caused by the discontinuation of the flow control valve include the occurrence of pressure pulsations and noise in a condition where a large quantity of air is entrained in the fluid. These issues were resolved by applying the following approaches to the oil pump of the CVT W/R.

- Prevention of air entrainment by enlarging the suction passage
- Optimization of the pressure rise from the low pressure chamber to the high pressure chamber
- Reduction of air content in the fluid by optimizing fluid flow inside the transmission

The measures implemented in this regard are described in detail below.

#### 3.1 Prevention of air entrainment by enlarging the inlet port

The vane oil pump used with the existing Jatco CVT7 is designed with an inlet port shape for optimizing the return pressure from the flow control valve. For the CVT7 W/R, however, the shape of the inlet port was optimized for inhibiting air entrainment.



Fig. 5 Shape of camring

Figure 4 presents simulation results showing the pressure distribution at the inlet port of the two oil pumps. With the inlet port shape of the existing CVT7, unevenness is seen in the pressure distribution under a condition where the return pressure from the flow control valve is not applied. With this shape, air is entrained at local low pressure areas.

The issue of this shape is that the narrow passage just before the fluid enters the vane chamber induces air entrainment. As a solution to this issue, a notch was provided in the vane sliding surface as shown in Fig. 5.

Providing this notch expands the passage just before the vane chamber, but it narrows the area of the vane sliding surface and thus raises the surface pressure. Therefore, the shape of the cam ring was optimized by carefully determining the limits of the intake port area and the part strength.

### 3.2. 低圧室から高圧室への油圧立ち上がり最適化

流量制御弁によるリターン圧が加わらない構造では、低圧の吸入回路から高圧の吐出回路への圧力受け渡し時の昇圧タイミングが遅れ、脈動が発生しやすくなる。本傾向は、高エア含有時に特に顕著に現れる。

CVT7 W/Rでは本課題に対してFig.6のような溝をベーン室の低圧室から高圧室への受け渡し部に設け、油圧立ち上がりタイミングを従来の流量制御弁付きのものと同等にした。

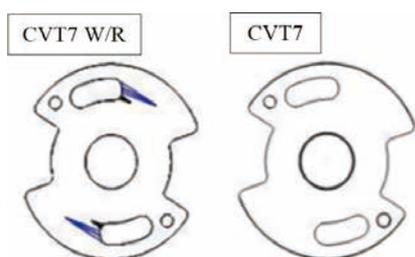


Fig. 6 Shape of groove at side plate

溝追加による昇圧タイミングの実測結果をFig.7に、脈動の実測結果をFig.8に示す。

溝の長さは長くすればするほど脈動が減る傾向にあるが、溝を伸ばしすぎると低圧室と高圧室がつながり、リークが発生することで吐出流量が低下してしまうため、吐出量の低下が起こらない限界を見極めて最適設計した。

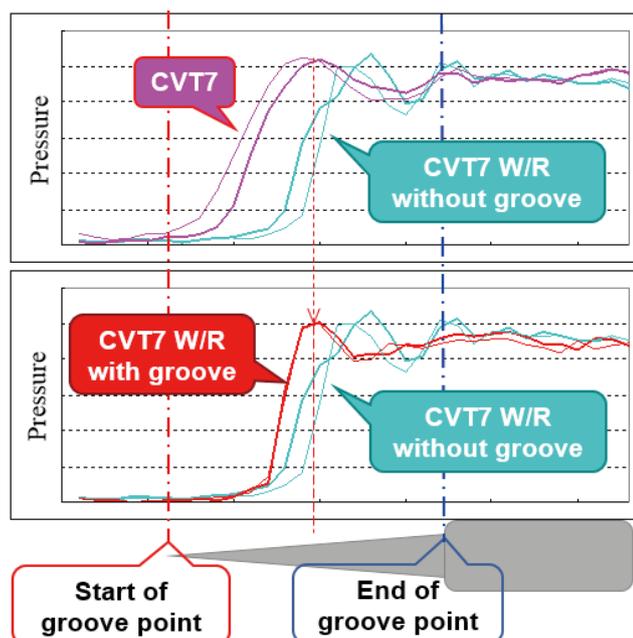


Fig. 7 Pressure of vane room

### 3.2 Optimization of pressure rise from low pressure chamber to high pressure chamber

With the structure where the return pressure from the flow control valve is not applied, the pressure rise timing in the pressure transfer from the low pressure suction circuit to the high pressure discharge circuit is delayed, which tends to cause pressure pulsations. This tendency is especially pronounced when the fluid has a high air content.

As a measure to prevent this issue in the oil pump of the CVT7 W/R, grooves are provided in the side plate, as shown in Fig. 6, where the transfer from the low pressure chamber to the high pressure chamber occurs in the vane chamber. This measure achieves the same pressure rise timing as that of the existing pump with the flow control valve.

The measured pressure rise timings with and without the grooves are compared in Fig. 7, and the measured pressure pulsation results are shown in Fig. 8. It is seen that the pressure pulsations tended to decrease with a longer groove length. However, making the grooves too long would connect the low and high pressure chambers, resulting in leakage that would lower the discharge flow rate. Therefore, the groove length was optimally designed by carefully determining the limit at which the discharge flow rate would not decline.

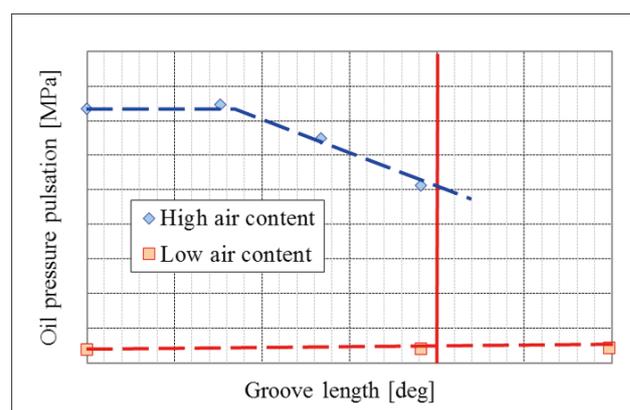


Fig. 8 Oil pressure pulsation by the groove length

### 3.3. ユニット内部流れ最適化によるエア含有率低減

CVT7 W/Rではオイルポンプのエア含有率に対する耐力を向上させるだけではなく、ユニットで発生するエアを抑制する構造も取り入れた。

オイルポンプはチェーンで駆動されるが、チェーンがオイルを攪拌することでオイル中のエア含有率が上がることが分かっている。エアを低減させるためにはファイナルギヤでの攪拌流とチェーンでの攪拌流がぶつかり合うことを低減させることが必要となる。

そこで、ファイナルギヤの攪拌流とチェーンの攪拌流を分離し、また、これまでチェーンでの攪拌流を阻害して飛散を抑えていたのを、特定の方向へと敢えて飛散させることで再攪拌頻度を減らしてエア含有率低減を行った (Fig.9)。

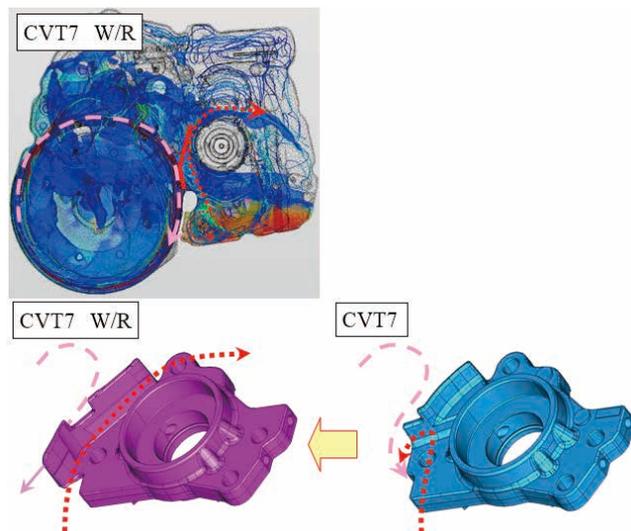


Fig. 9 Oil flow inside the unit and around pump chain

他にも、プーリー室に侵入したオイルを積極的に抜く構造、ファイナルギヤ攪拌を減らす構造、オイルパン形状およびストレーナ吸い口位置を最適化し、オイルレベルを下げることで攪拌量を減らす等のユニット内部流れを最適化することでエア含有率を下げる構造を採用した。これら構造を採用することで従来よりも約30%エア含有率低減させている。

CVT7 W/RはFig.10に示すようにオイルポンプの構造変更に加え、オイル中のエア含有率を下げることで脈動を目標値以下にすることが出来た。

### 3.3 Reduction of air content in the fluid by optimizing fluid flow inside the transmission

In addition to improving the strength of the oil pump against the air content in the fluid, the structure of the CVT7 W/R unit was also designed to inhibit air entrainment.

It was observed that fluid churning caused by the chain for driving the oil pump increased the air content in the fluid. In order to reduce the air content, it was necessary to mitigate the colliding of the churning flow produced by the final gear and that produced by the chain.

To accomplish that, the churning flow of the final gear and that of the chain were separated. In addition, whereas fluid splashing was previously suppressed by inhibiting the churning flow of the chain, the fluid was deliberately allowed to splash in a specific direction so as to reduce the frequency of re-churning and thereby lower the air content (Fig. 9).

Other structures were also adopted to reduce the air content by optimizing the fluid flow inside the transmission. These include a structure for actively draining fluid that ingresses into the pulley chambers, a structure for reducing churning produced by the final gear, optimization of the oil pan shape and position of the oil strainer inlet, and reduction of churning by lowering the fluid level. The adoption of these structures reduced the air content by approximately 30% compared with the existing CVT7.

As shown in Fig. 10, the pressure pulsation level in the CVT7 W/R was reduced below the target by lowering the air content in the fluid, in addition to making the foregoing structural changes to the oil pump.

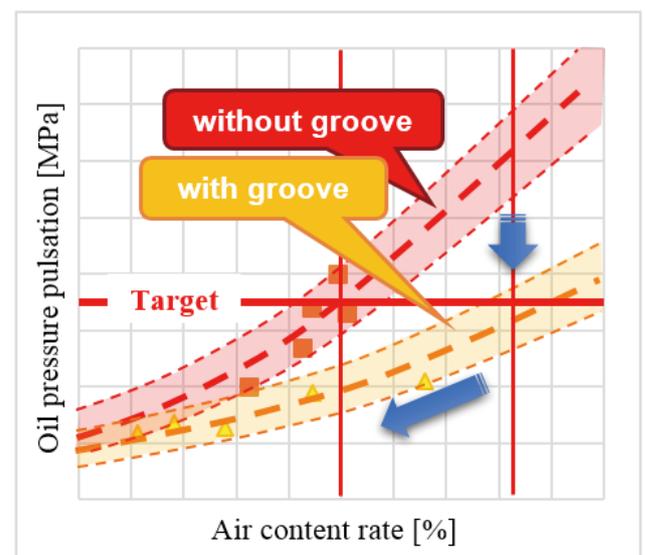


Fig. 10 Oil pressure pulsation by the air content rate

## 4. オイルポンプ効率

## 4. The oil pump efficiency

Fig.11に実測したオイルポンプ効率を示す。環状リークの解消による容積効率の向上および、オリフィス抵抗解消による機械効率の向上の二つの効果により、全効率の向上が実現でき、世界一水準の高効率である。

Figure 11 compares the measured oil pump efficiency. Volumetric efficiency was improved by eliminating annular leakage and mechanical efficiency was improved by eliminating flow resistance through the orifice for activating the flow control valve. The effects of these two improvements have boosted the overall pump efficiency to the highest level among similar pumps worldwide.

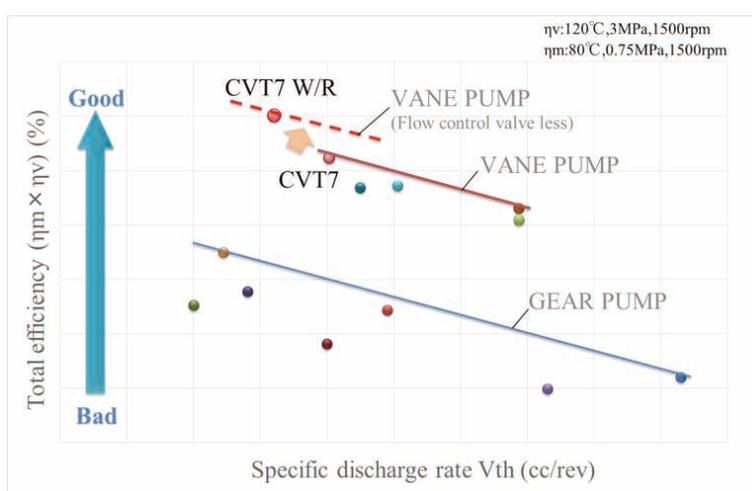


Fig. 11 Comparison of Oil pump efficiency

## 5. まとめ

## 5. Conclusion

CVT7 W/Rではオイルポンプの改良だけでなく、ユニットシステムとして最適化することで従来成し得なかった流量制御廃止を実現し、オイルポンプ効率世界一の水準を達成することが出来た。

最後に、本オイルポンプ開発にあたり多大なご協力をいただいたKYB株式会社の関係者および社内外の多くの方々に深く感謝する。

In addition to the improvements made to the oil pump, the overall system of the CVT7 W/R was optimized. That allowed the flow control valve to be discontinued, which was not possible previously, and enabled the oil pump to achieve the world's highest level of efficiency.

Finally, the authors would like to thank the people involved at KYB Corporation and many other individuals inside and outside the company for their invaluable cooperation with the development of the new oil pump.

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# 小型・高精度油圧センサの開発

Development of a Compact, High-accuracy Pressure Sensor

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**抄 録** Jatco CVT7 W/R(以下 CVT7 W/R)において、高効率、小型軽量化に貢献するために、CVT専用の新型油圧センサの開発を行った。この油圧センサの油圧精度ばらつきは、従来比で60%低減(\*1)、部品のHEXサイズは12mmで従来比50%小型化(\*2)した、本稿では新型センサについて紹介する。

(\*1)(\*2)効果詳細は、開発部品の効果を参照方

**Summary** A dedicated CVT pressure sensor was newly developed to help reduce the size and weight of the Jatco CVT7 W/R and improve its efficiency. This pressure sensor reduces the variability in pressure detection accuracy by 60% compared with the previous sensor. The 12-mm size of the hexagonal nut for attaching the sensor is 50% smaller than previously. The related details are explained in the sections concerning the benefits of the new pressure sensor. This article describes the development of this new sensor.

## 1. はじめに

## 1. Introduction

市場から燃費の向上を目的に、CVTユニットに高効率化・小型軽量化が求められている。

高効率化を実現させるには、変速制御の精密化が必要となり、油圧センサの高精度化が必須である。

CVTユニットの小型化には、搭載性を改善する小型の油圧センサが必要と考えた。

油圧センサの高精度・小型化のうち小型化は、車両のブレーキアプリケーションに内蔵搭載されているゲージ圧式の小型油圧センサの技術応用での対応が考えられた。しかし、CVTユニット用油圧センサと、車両ブレーキ用油圧センサでは、必要とされる圧力領域の違いと、センサの搭載環境の違いにより、新たにCVT専用の油圧センサ開発が必要となった(Fig.1)。

CVT7 W/Rでは、これら車両ブレーキ用油圧センサと異なる二点を重要課題として、高精度化・小型化のCVT専用油圧センサの新開発に取り組んだ。

### 重要課題

- ・CVT向け低圧領域での高精度化
- ・CVT環境での使用

以下、詳細について紹介する。

There are strong market demands for smaller, lighter and more efficient CVTs for the purpose of improving vehicle fuel economy. Achieving higher efficiency requires more precise shift control, for which pressure sensors with higher accuracy are indispensable. We reasoned that a compact pressure sensor with improved mountability was necessary for downsizing CVTs.

Compact gauge pressure sensors are mounted inside vehicle braking systems. It was reasoned that this existing sensor technology could be applied to downsize the CVT pressure sensor and thereby accomplish one of the requirements for a smaller, more accurate CVT pressure sensor. However, the pressure range that must be detected differs between the pressure sensors used in vehicle braking systems and those used for CVTs. In addition, the environment where the sensor is installed differs between the two applications. For these reasons, it was necessary to develop a new pressure sensor specifically for CVT application (Fig. 1).

These two differences from the pressure sensors used in braking systems were addressed as priority issues in developing a new compact, high-accuracy, dedicated CVT pressure sensor for the CVT7 W/R.

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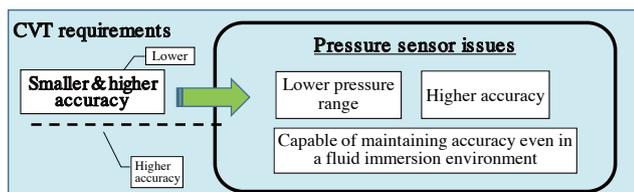


Fig. 1 CVT requirements and pressure sensor issues

## 2. CVT向け低圧領域での高精度化

### 2.1. 開発課題と方策

新開発するCVT用油圧センサでは、圧力検知部に車載実績のある車両ブレーキ用油圧センサの受圧部の歪を検出する構造(歪ゲージ式)を用いた(Fig.2)。

しかし、検出圧力が高圧領域の車両ブレーキ用油圧センサに対し、CVTユニットでは低圧領域を用途とするので、センサの受圧部への印加圧は低く、歪は微小となる。この微小な歪をとらえるにあたり、センサの個体差を考慮すると、CVTで必要とする圧力領域での精度達成が困難であった。

本開発では、CVTユニットで多用される温度領域と圧力領域のセンサ歪特性を油圧センサの検査工程で一つ一つ個体検査し、この測定した結果を油圧センサに内蔵した記憶領域にキャリブレーション値として保存し、油圧センサ出力値を補正させることで精度課題を克服した。

### 2.2. 開発部品の効果

新開発した油圧センサの出力精度は、温度60℃～100℃の温度範囲で、CVTで多用する0MPa～1.5MPaの圧力領域において、従来センサ比で60%の精度向上を達成した。

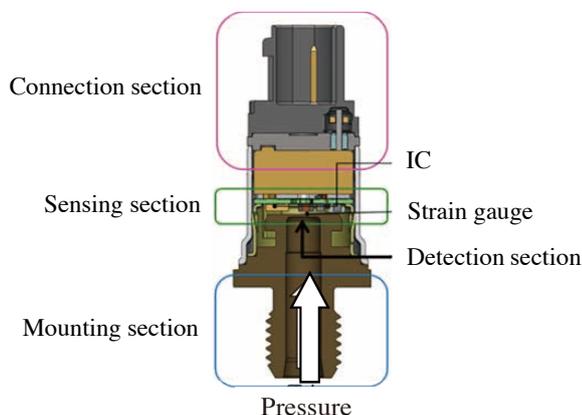


Fig. 2 Cross-sectional view of new pressure sensor

The priority issues were:

- To achieve higher accuracy in the low pressure range for CVT application
- To develop a sensor for use in the CVT environment

The following sections describe in detail how these issues were addressed in developing the new pressure sensor.

## 2. Improvement of Accuracy in Low Pressure Range for CVT Application

### 2.1 Development issue and solution

A strain gauge was adopted in the pressure detection section of the newly developed CVT pressure sensor as the sensing element for detecting the amount of strain on the diaphragm (Fig. 2). This type of sensor structure has a track record of use in vehicle braking systems.

However, whereas the pressure sensors used in vehicle braking systems detect pressures in the high pressure range, CVT pressure sensors must be able to detect pressures in the low pressure range. Consequently, the pressures applied to the sensor diaphragm are low and the strain levels are tiny. Considering the tiny strain levels to be detected and given the variability among individual sensors, it was felt that it would be difficult to achieve the necessary degree of detection accuracy in the low pressure range required for CVT application.

Strain sensing characteristics in the many different temperature ranges and pressure ranges used in CVTs are examined for individual sensors in the sensor inspection process. The measured results are stored as calibration values in the memory area built into the new pressure sensor. Those values are used to compensate the output value of the pressure sensor. This approach made it possible to overcome the accuracy issue in this sensor development project.

### 2.2 Benefit of newly developed sensor

The new pressure sensor achieves output accuracy that is 60% higher than that of the previous sensor. This improved output accuracy is achieved in a pressure range of 0 MPa to 1.5 MPa, which is often used in CVTs, and in a temperature range of 60°-100°C.

### 3. CVT環境での小型化センサの開発

#### 3.1. 開発課題と方策

CVT用油圧センサは、トランスミッションの内側に搭載するため、CVTオイル噴霧または油中が使用環境となる。本開発の小型化技術に、車両ブレーキ用のゲージ圧式油圧センサの技術の応用を考えた。しかし、部品の使用環境の違いで2つの課題があり、新たな油圧センサ構造を確立する必要があった。

1つ目は、CVTユニットの内圧がセンサ内側に加わることで検出圧ずれ、2つ目は、CVTオイルがセンサ内側に入ることで回路故障の懸念である。

2つの課題に対応するセンサ構造としては、新たにシールドゲージ圧式センサとすることで、センサ外部からの密閉環境とできるため2つの課題は解決できる(Fig.3)。

しかし、シールドゲージ圧式の密閉構造にしたことで、新たに、センサの検出圧力の精度に温度での空気の膨張・収縮によるセンサ内圧変化が影響する。

センサの検出圧力の精度は、検圧部の歪量で決まる。センサ内圧が変化すると、センサに加わる油圧の差圧がずれ、精度の悪化を招く。このため、空気圧を漏らさない確実な気密性維持の技術が求められた。

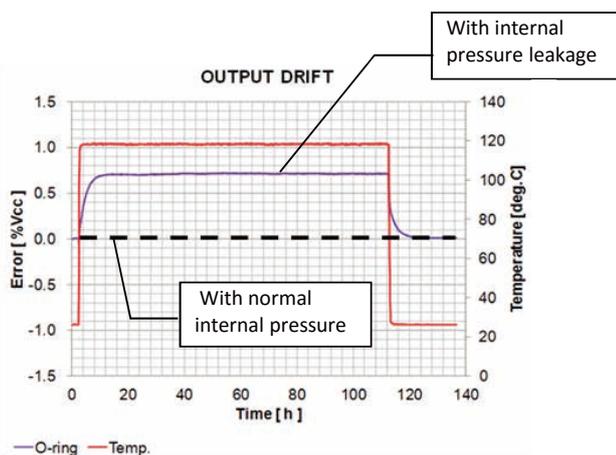


Fig. 4 Leakage of internal sensor pressure and impact on output

Fig.4に、気密性維持の機能を簡易的にOリングで実施した事例を示す。一定温度保持中にセンサの内圧が漏れて、出力ズレが発生した出力波形である。簡易的なシールド構造ではセンサの内圧漏れが発生し、検圧部の歪量がずれて出力精度を低下させる原因となった。

### 3. Development of a Compact Sensor for the CVT Environment

#### 3.1 Development issue and solution

Because a CVT pressure sensor is installed inside the transmission, the device is used in an environment where it is immersed in the CVT fluid or mist. As a way of downsizing the new pressure sensor, we considered applying the technology of the gauge pressure sensor used in vehicle braking systems. However, the difference in usage environments gave rise to two issues, making it necessary to establish a new pressure sensor structure.

The first issue involved detected pressure error owing to the application of the internal pressure in the CVT on the sensor interior. The second issue was concern about circuit failure due to incursion of CVT fluid into the sensor.

A sealed gauge pressure sensor was newly adopted as the sensor structure for addressing these two issues. Because this type creates a sensing environment that is tightly sealed from the sensor's external surroundings, both issues can be solved (Fig. 3).

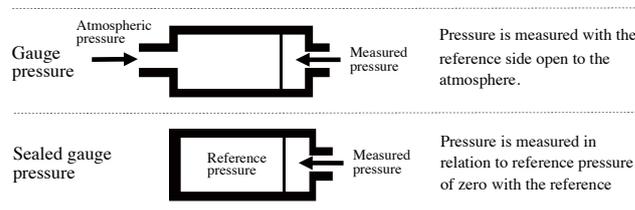


Fig. 3 Difference in reference pressure between sensors

However, adopting the hermetic structure of a sealed gauge pressure sensor raised a new issue in that pressure detection accuracy would be influenced by changes in the internal pressure of the sensor due to temperature-induced expansion and contraction of the air.

The accuracy of the pressure detected by the sensor is determined by the amount of strain occurring in the detection section. If the pressure inside the sensor changes, the differential pressure of the pressure applied to the sensor will deviate, causing accuracy to decline. Solving that issue required a technique for reliably maintaining airtightness so that the air pressure inside the sensor would not leak out.

Figure 4 presents an example of the results obtained when a simple O-ring was applied as the sealing function for maintaining airtightness. The output waveform shows the occurrence of output drift due to leakage of the internal

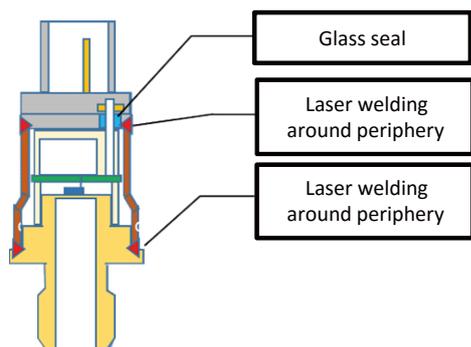


Fig. 5 Creation of tightly sealed sensor state

本開発では、Fig.5に示すように油圧センサでは初採用となる円周部レーザー溶接および電極部ガラスシールを採用することで、完全密封による出力精度の安定化を達成した。

### 3.2. 開発部品の効果

部品サイズの一例としてセンサ組み付け工具の六角幅を事例にすると、HEXサイズは、従来品24mm→開発品12mmと50%のサイズダウンを達成した(Fig.6)。

### 3.3. コントロールバルブへの搭載性

新開発のCVT用油圧センサで、CVT7 W/R用コントロールバルブに3個が配置可能となる。これは、従来の油圧センサでは達成できなかった配置であり、新開発の小型センサがコントロールバルブの小型化に大きな貢献をした(Fig.7)。

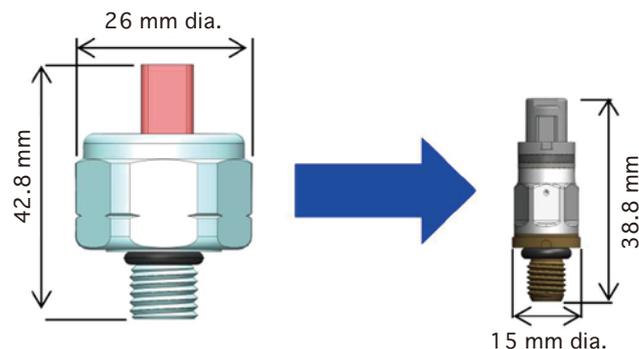


Fig. 6 Comparison of sensor pressure sizes

pressure of the sensor under a condition of a constant temperature. With this simple sealing structure, leakage of the internal pressure of the sensor caused the amount of strain in the detection section to deviate, thus causing output accuracy to decline.

For the new pressure sensor, laser welding was applied for the first time around the periphery of the sensor and a glass seal was applied to the electrode section, as shown in Fig. 5. These measures ensure stable output accuracy by creating a completely sealed state.

### 3.2 Benefit of newly developed sensor

Figure 6 presents one example of a comparison of the pressure sensor sizes. For example, the size of the hexagonal nut for attaching the sensor was reduced by 50% from 24 mm previously to 12 mm for the new pressure sensor.

### 3.3 Mountability to control valve

The reduced size of the newly developed CVT pressure sensor allows for the installation of three sensors on the control valve of the CVT7 W/R. This smaller sensor size contributed greatly to the downsizing of the control valve, something that was not possible with the previous pressure sensor (Fig. 7).

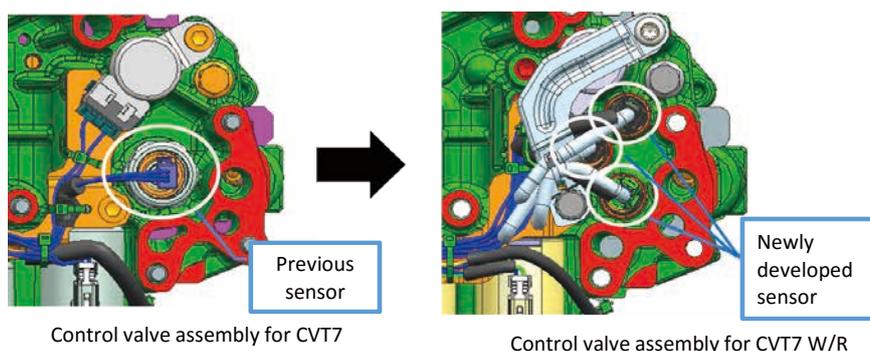


Fig. 7 Comparison of mountability on control valve

#### 4. まとめ

新型の油圧センサの高精度化は、CVT7 W/Rにおいてパワートレイン効率の向上に貢献した。CVTユニット用の油圧センサとしても、トップクラスの小型品が開発できた。

また、キャリブレーションプロセスの最適化と新方式シールを採用した高精度・小型油圧センサを開発し、CVTの小型・軽量・燃費向上に貢献できた。

本開発に当たり、多大なるご協力をいただいた株式会社センサータ・テクノロジーズジャパン関係諸氏および社内外関係者の方々に厚く感謝を申し上げる。

#### 4. Conclusion

The increased accuracy of the new pressure sensor contributes to improvement in powertrain efficiency of the CVT7 W/R. This new sensor is one of the smallest pressure sensors ever developed for CVT application.

And a compact, high-accuracy pressure sensor was developed by optimizing the calibration process and adopting a new sealing method. This new sensor contributed to making the CVT7 W/R smaller and lighter for improved fuel economy.

The authors would like to deeply thank the people concerned at Sensata Technologies, Inc. for their invaluable cooperation with the development of the new pressure sensor and also everyone else who contributed to this development project.

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# 低フリクションシールベアリングの開発

Development of a Low-friction Sealed Bearing for a Steel-belt CVT

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**抄 録** ジヤトコは新たに副変速機付小型FF車用ベルトCVTとしてJatco CVT7 W/R(以下, CVT7 W/R)を追加開発した。この新開発ユニットは従来の副変速機付CVTに対して小型軽量化による優れた車両搭載性を犠牲にすることなく、運転性能と燃費性能の大幅な向上を達成しており、そのために数々の新技術が投入されている。

本稿では、それら新技術の一つとして、燃費性能と信頼性を高いレベルで両立するため、新たにプーリー支持ベアリング向けに日本精工株式会社と共同開発した低フリクションシールベアリングについて紹介する。

**Summary** The new Jatco CVT7 W/R with an auxiliary gearbox was developed as an additional next-generation steel-belt CVT for front-wheel-drive cars. This new CVT achieves large improvements in driveability and fuel economy over the existing base CVT with an auxiliary gearbox without sacrificing the excellent vehicle mountability attributable to its compact, lightweight package. Numerous new technical features were adopted to achieve this performance.

This article describes one of these new technical features represented by a new low-friction sealed bearing that was jointly developed with NSK, Ltd. for use as a new pulley-support bearing. This new sealed bearing achieves optimal levels of both fuel economy and reliability.

## 1. はじめに

新たに開発したCVT7 W/Rでは、従来機種の特徴である小型軽量化による優れた車両搭載性を犠牲にすることなく、運転性能と燃費性能の向上を達成している。特に燃費性能向上に対しては、変速比幅の拡大や各部のフリクション低減を実現した。

Fig.1に従来の副変速機付ベルトCVTにおけるフリクションの内訳を示す。図よりユニット全体に占めるベアリングのフリクションは無視できないことがわかる。その一方で、ベアリングは静粛性が高く滑らかな動力伝達には欠くことのできない精密部品である。その構成要素である転動体や軌道輪の転走面に傷や剥離が存在すると、異音や振動が発生し、滑らかな運転性能を大きく損なうこととなる。そのような問題を引き起こす原因の一つとして、潤滑油に混入した機械加工時の切粉や摩耗粉などの硬質な夾雑物がベアリング内部に侵入して転動面に噛み込む事例が報告されている。対策としては、部品の製造工程やユニットの組立工程において、夾雑物の混入

## 1. Introduction

The newly developed CVT7 W/R improves both driveability and fuel economy without sacrificing the outstanding vehicle mountability characterizing the existing base model and attributable to the compact size and light weight. To improve fuel economy in particular, the ratio coverage of this new CVT was expanded and the friction levels of various parts were reduced.

Figure 1 shows a friction breakdown for the existing steel-belt CVT with an auxiliary gearbox. It is clear from the figure that the bearings' share of the unit's overall friction is too large to ignore. On the other hand, bearings are precision parts that are indispensable to the quiet and smooth transmission of power. The presence of scratches or peeling on the rolling surfaces of the rolling elements and raceways that are component parts of the bearings can produce abnormal noise or vibration, which greatly affects smooth driveability. One reported cause of such problems is the intrusion into the bearing interior of hard foreign particles that gouge the rolling surfaces.(1) Such foreign particles include chips and wear debris contained in

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防止に細心の注意を払うとともに、必要な部位には内部への夾雑物侵入を防ぐためにシールベアリングを採用している。ただし、従来のシールベアリングでは、シールの摺動による摩擦トルクがフリクションを増加させるという課題があった。

そこで、筆者らは低フリクション性能と信頼性を高いレベルで両立させるために、プーリ支持ベアリング用の低フリクションシールベアリングを開発した。本稿ではその技術内容について紹介する。

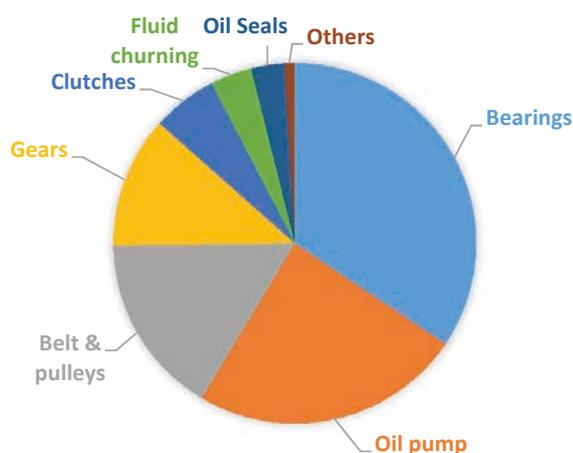


Fig. 1 Friction breakdown for existing steel-belt CVT with an auxiliary gearbox

## 2. プーリ支持ベアリングへの要求性能

CVT7 W/Rの断面図をFig.2に示す。プーリ支持ベアリングは図中に示すように、入力側と出力側のそれぞれのプーリ軸部に圧入されており、CVTベルトからの張力や、ギアのかみ合い反力を支えながら、各プーリを滑らかに回転させる機能が求められる。

プーリ支持ベアリングには、前述したCVTベルトの張力や、ギアのかみ合い反力といった入力荷重に適した負荷能力を有し、かつ転がり抵抗の少ない深溝玉軸受を採用する事例が多い。Fig.3にプーリ支持ベアリングに使用しているシールベアリングの構造を示す。図中に示すように、シールは鉄製の芯金の周囲にアクリルゴムをリップ形状に成形しており、外輪の両端面に固定し、リップ先端部を内輪に設けた溝の側面と接触させながら回転方向に摺動させている。このラビリンス形状のシール構造により、夾雑物の内部への侵入防止が可能となる反面で、その摺動による摩擦トルクがフリクション増加の原因となっていた。

the lubricating oil at the time of machining. One measure against foreign particles is to exercise extreme care to prevent their incursion during parts manufacturing and transmission assembly processes. Another measure is to apply sealed ball bearings wherever necessary to prevent foreign particles from intruding into the interior of products. However, conventional sealed bearings have had a problem that the sliding of the seals produces friction torque that increases friction.

Therefore, to achieve optimal levels of both low friction performance and high reliability, we developed a new low-friction sealed bearing for use in supporting the pulleys. This article describes the technical details of the newly developed bearing.

## 2. Performance Required of Pulley-support Bearings

Figure 2 is a cross-sectional view showing the structure of the CVT7 W/R. As shown in the figure, a pulley-support bearing is press fitted on both the input and output pulley shafts. The function required of the bearings is to enable each pulley to turn smoothly while supporting the tension received from the CVT belt and the reaction forces of gear meshing.

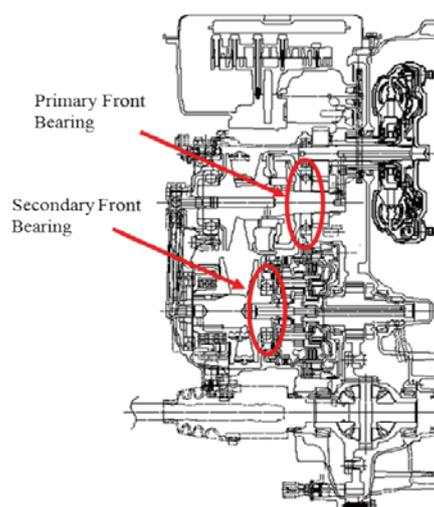
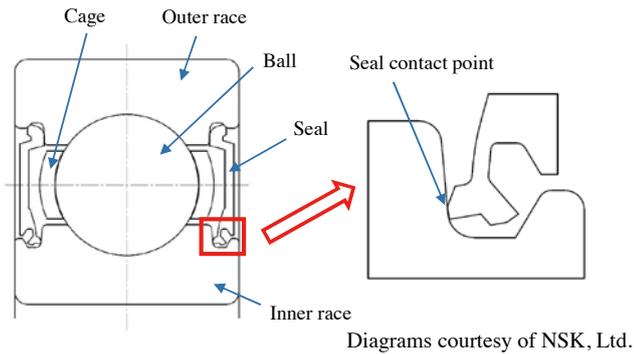


Fig. 2 Schematic structure of CVT7 W/R

Deep-groove radial ball bearings are often used as pulley-support bearings because they possess load capacity suitable for handling input loads such as the tension from the CVT belt and the reaction forces of gear meshing, besides also having a low level of rolling resistance. Figure 3 shows the structure of the sealed ball bearing used as a pulley-support bearing. As illustrated in the figure, the seal is formed of



Diagrams courtesy of NSK, Ltd.

Fig. 3 Structure of sealed ball bearing

### 3. 低フリクションシールベアリングの開発

#### 3.1. 開発のコンセプト

従来のシールベアリングでは、信頼性確保の観点から、運転中に想定されるさまざまな荷重、温度などの使用条件、および構成部品の寸法公差や、組み立て時の変形量など、あらゆる条件下でシール部に締め代をもたせる設計であったため、常に摩擦トルクが発生していた。それに対して、本稿の低フリクションシールの開発にあたっては、以下のコンセプトにより、信頼性と低フリクションの両立を実現することとした。

- 1) 想定される最も厳しい使用条件、および精度の変動下においても、許容サイズを超える夾雑物の内部への侵入を防止できること。
- 2) 高回転となる出力側プーリーへの適用時でもリップ部の摩耗、焼き付きが発生しないこと。
- 3) 前記の1)、2)を満足した上で、可能な限り、リップ先端部と内輪溝側面の間のすきま(以下、シールすきまと呼ぶ)を付与することにより、摩擦トルクを大幅に低減すること。

#### 3.2. シールすきまと侵入夾雑物サイズの関係

シールすきま量とベアリング内部に侵入する夾雑物サイズの関係进行调查するため、異なる3水準のシールすきまを有するシールベアリング、およびシールを装着していないベアリング(以下、オープンベアリングと呼ぶ)を用いて、夾雑物入り潤滑油中で運転試験を行った。夾雑物は異なる2種類の粒径分布をもつスティールグリッドを使用した。試験はTable 1の条件で24時間運転した後、ベアリング内部に侵入した夾雑物のサイズを調査した。結果をFig.4に示す。図の横軸は試験条件における各シールベ

acrylic rubber in a lip shape surrounding the steel core bar. It is fixed to both end faces of the outer race and the tip of the lip slides in the direction of rotation while in contact with the side surface of the groove provided in the inner race. While this labyrinth seal structure prevents the incursion of foreign particles into the bearing interior, its sliding motion produces friction torque that causes greater friction.

### 3. Development of Low-friction Bearing

#### 3.1. Development concepts

The seal of existing sealed ball bearings constantly produces friction torque because it is designed with a tightening margin against all sorts of conditions for the sake of ensuring reliability. These include usage conditions such as various loads and temperatures envisioned during driving, dimensional tolerances of the component parts, and deformation that occurs during assembly, among other things. The following concepts were adopted for the development of the new low-friction sealed bearing described here in order to achieve both reliability and low friction.

- (1) The seal must be able to prevent incursion into the bearing interior of foreign particles exceeding an allowable size even under the severest usage conditions envisioned and accuracy fluctuations.
- (2) The lip portion must not wear or suffer seizure even when applied to the output pulley that rotates at high speed.
- (3) In addition to satisfying the two conditions above, friction torque must be greatly reduced by allowing the largest possible clearance, referred to here as seal clearance, between the lip tip and the side surface of the inner race groove.

#### 3.2. Relationship between seal clearance and size of intruding foreign particles

An investigation was made of the relationship between the amount of seal clearance and the size of foreign particles intruding into the bearing interior. Operating tests were conducted in lubricating oil containing foreign particles using sealed ball bearings with three different levels of seal clearance and an unsealed or open ball bearing. The foreign particles used were steel grits having two different particle diameter distributions. The operating test was conducted for 24 hr under the conditions in Table 1 and then the size of the foreign particles that intruded into the bearing interior was investigated. The results are shown in Fig. 4. The minimum size of the foreign particles used in the test

Table 1 Conditions of steel perticle instruction test

Radial load	12800N
Rotational speed	2000rpm
Lubricant	CVT fluid
Oil temperature	120°C
Amount of steel perticles	0.2g/L

アリングのシールすきまの計算値、および縦軸は試験に使用した各夾雑物の粒径の下限値である。図に示すように、侵入する夾雑物のサイズが許容値を超えないようにシールすきまの上限値を決定した。

### 3.3. シールすきまと耐摩耗，耐焼き付き性の関係

前節で決定したシールすきまの上限値を採用した場合、実際の運転中には各軌道輪と転動体の軸方向すきまや、内輪の傾きなどにより、シール部に締め代が発生する状況も想定される。特に出力側プリー軸は最高回転数が10000rpm以上の高回転となることから、シール締め代による面圧が許容値を超える場合には、シールの摩耗や焼き付きの発生が懸念される。そこで、シール締め代を3水準に設定したシールベアリングを試作し、Table 2に示す条件で、高回転におけるシール耐久性を調査した。ここでベアリングへの給油方法はユニット内の潤滑条件を模擬するために、Fig.5に示すようにベアリング側面からの強制給油とし、給油量も実機と同様とした。試験結果をFig.6に示す。なお、図中の縦軸は、Fig.7に示すシール形状モデルを用いて、有限要素法により各シール締め代における接触面圧を求めた解析結果である。Fig.6に示すように、潤滑の厳しい反給油側で許容面圧を超えないようにシール締め代の上限値を決定した。

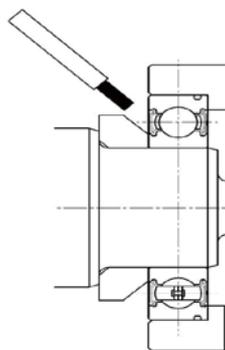


Diagram courtesy of NSK, Ltd.

Fig. 5 Lubrication method

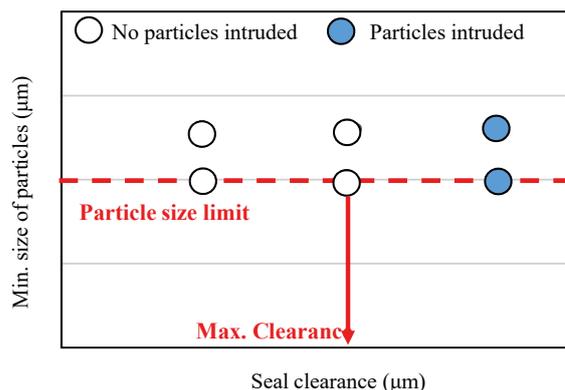


Fig. 4 Results of particle intrusion test

is shown on the vertical axis in relation to the calculated seal clearances of the sealed ball bearings on the horizontal axis. As indicated in the figure, an upper limit of the seal clearance was determined so that the size of the intruding particles did not exceed the allowed value.

### 3.3. Relationship between seal clearance and wear and seizure resistance

Under the assumption that the upper limit of the seal clearance was adopted as mentioned above, conditions were also assumed for the tightening margin of the seal that would occur during actual operation due to the axial clearance of the raceways and rolling elements, inclination of the inner race and other factors. Because the output pulley shaft in particular rotates at a maximum speed higher than 10000 rpm, there was concern that the seal might wear or suffer seizure if the contact pressure due to the tightening margin exceeded the allowable value. Therefore, prototype sealed ball bearings with three different levels of tightening margin were manufactured and seal durability was investigated in high-speed operation under the test conditions shown in Table 2. The method of supplying lubricant to the bearings in the test simulated the lubrication condition in an actual CVT. As shown in Fig. 5, forced lubrication was provided from the bearing side and the quantity of lubricant supplied was identical to that of an actual CVT.

Table 2 Wear test conditions

Interference of seal lip	250 μm
Radial load	0N
Rotational speed	10450rpm
Lubricant	CVT fluid
Oil temperature	110°C

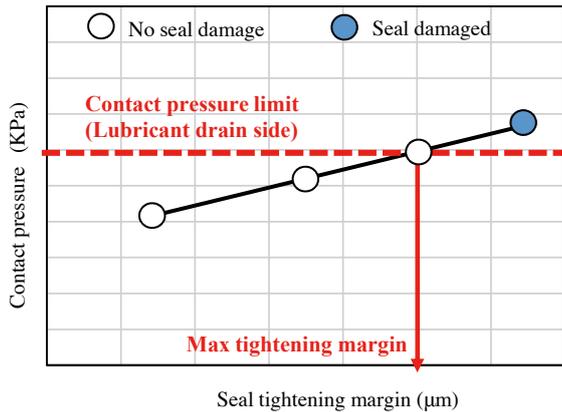


Fig. 6 Results of seal wear test

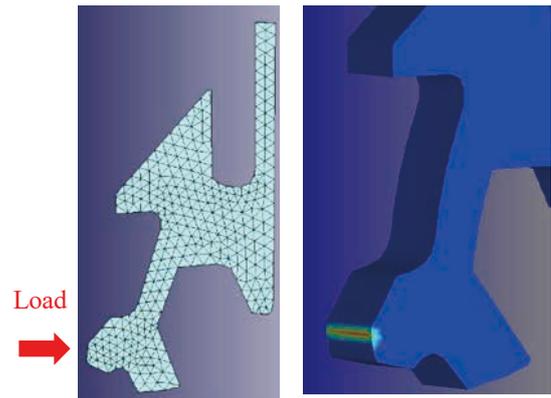


Fig. 7 FEM analysis model

### 3.4. フリクション低減効果の確認

前節までで決定したシールすきま、およびシール締め代の上限値を、いずれも満足するよう設計した低フリクションシールベアリングの効果を確認するため、フリクション測定試験を実施した。試験では従来のシールベアリング、およびオープンベアリングとの比較を行った。試験結果をFig.8に示す。試験条件は、回転数1500rpm、CVTフルードの油温80℃、油面高さを最下転動体位置とした。Fig. 8より、低フリクションシールベアリングは、オープンベアリングには及ばないものの、従来のシールベアリングに対して47%の大幅なフリクション低減を実現できることが分かった。本開発の低フリクションシールベアリングはFig.2に示すプライマリーフロントベアリングとセカンダリーフロントベアリングの2箇所に採用している。

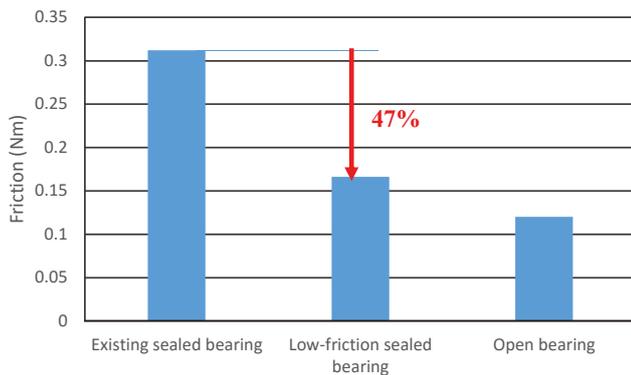


Fig. 8 Results of friction measurement

The results of the seal wear test are shown in Fig. 6. The contact pressure on the vertical axis was found using the finite element simulation model shown in Fig. 7. The contact pressure was calculated with this model at each seal tightening margin using the finite element method. As shown in the Fig. 6, an upper limit was determined for the seal tightening margin so that the contact pressure did not exceed the allowable level on the lubricant drain side where the lubrication condition was severe.

### 3.4. Confirmation of friction reduction effect

Friction measurement tests were then conducted to confirm the effect of the low-friction sealed bearing that was designed so as to satisfy both the seal clearance and the upper tightening margin limit that were determined as described above. In these tests a comparison was made with the existing sealed bearing and an open bearing. The measured results are shown in Fig. 8. The test conditions were an operating speed of 1500 rpm, a CVT fluid temperature of 80℃ and a fluid height equal to the lowest position of the rolling elements.

The results show that the new low-friction bearing reduces friction by a large 47% from the level of the existing sealed bearing, though the reduction does not equal that of the open bearing. The newly developed low-friction sealed bearing has been adopted in two locations, namely, as the primary and secondary pulley front bearings as shown in Fig. 2.

## 4. まとめ

新開発のCVT7 W/Rの燃費性能を達成するためのフリクション低減策のひとつとして、低フリクションシールベアリングを開発し、プーリ支持ベアリングの2箇所を採用した。

その技術方策としては、1)あらゆる条件下で許容サイズ以上の夾雑物の侵入を防止するとともに、2)出力側プーリの最高回転数でも耐久性が確保可能なシールすきま量を実験、解析により求め、最適なシールすきま量を設定した。その結果、従来のシールベアリングに比較して47%のフリクション低減を可能とした。

なお、本開発にあたって多大なご協力をいただいた日本精工株式会社、および社内関係各位に紙面を借りて感謝の意を表す。

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## 4. Conclusion

A new low-friction sealed bearing was developed for the new CVT7 W/R as a friction reduction measure for further improving vehicle fuel economy. The new bearing has been adopted at two locations as pulley-support bearings. The technical approach taken was to design the optimal seal clearance for (1) preventing the intrusion of foreign particles above a certain allowable size under all sorts of conditions and (2) ensuring seal durability even under the maximum rotational speed of the output pulley. The seal clearance was determined on basis of experimental and simulation results. As a result, friction was reduced by 47% compared with an existing sealed bearing.

The authors would like to take this opportunity to express their appreciation to NSK, Ltd. and to everyone involved at JATCO for the invaluable cooperation received in this development project.

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# CAEを活用した攪拌フリクションの低減

Reduction of Churning Friction by using CAE Analysis

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**抄 録** 新開発のJatco CVT7 W/R(以下 CVT7 W/R)向けには燃費性能向上を目的にデフ部の攪拌フリクション低減仕様を開発した。トランスミッション内部全体をモデル化し、内部部品同士の隙間に発生する油の流れを過渡現象も含めて、且つ、気液混相流状況も加味して計算できるようにした。本稿では、攪拌低減のためのCAE活用について紹介する。

**Summary** Specifications for reducing churning friction in the differential chamber were developed for the newly developed Jatco CVT7 W/R (hereafter CVT7 W/R) with the aim of improving vehicle fuel economy. The entire interior of the transmission was modeled to facilitate calculations of fluid flow occurring in the clearances between the internal parts under transient operating conditions and also taking into account gas-liquid mixed flow. This article describes the use of CAE analysis to reduce churning friction.

## 1. はじめに

## 1. Introduction

当社では、攪拌フリクション低減への取り組みとして、油の低粘度化やバッフルプレートなどを採用している。

CVT7 W/Rでは、ケースの仕様変更のみでデフ部の攪拌フリクションを低減するために、CAEによる油の流れ解析を実施し最適仕様を決めた。これにより、デフ部の攪拌フリクションを改善仕様によって改善前に対して40%低減できた。

Measures taken at JATCO to reduce fluid churning include lowering the fluid viscosity and adopting baffle plates. For the CVT7 W/R, fluid churning in the differential chamber was reduced by just changing the specifications of the chamber and auxiliary gearbox case. That was accomplished by using computer-aided engineering (CAE) to conduct fluid flow analyses for determining the optimal specifications. As a result, the improved specifications reduced churning friction in the differential chamber by 40% compared with the friction level before the improvement.

## 2. 開発の狙い

## 2. Development Aim

デフ部の攪拌フリクションは回転体と油の接触面積に相関があるため、デフ室の油の無い気相領域が多いほど攪拌フリクションは小さくなる。CVT運転状態のデフ部にある油量についてはユニット全体の油の流れの設計が難しく、今までは可視化による実機検証などを行っていた(Fig.1)。

CVT7 W/R開発ではCAEにより運転状態の油の流れ解析を行い、デフ部の油量を低減できる仕様検討を行った。コスト競争力確保のために、バッフルプレートなどの部品を追加せずにケース形状の仕様変更のみで攪拌フリクションの低減を狙った。

Churning friction in the differential chamber correlates with the area of contact between the rotating parts and the fluid. This means that it decreases as the gas phase region without any fluid in the chamber increases. The quantity of fluid in the differential chamber under CVT operating conditions has been verified heretofore by conducting flow visualization tests because of the difficulty of designing the fluid flow throughout the entire transmission (Fig. 1).

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Fig. 1 Fluid flow visualization test

### 3. 課題

デフ部の攪拌フリクションを低減するためには、運転状態のデフ室の油量を低減し気相領域を増やすことがポイントとなる。運転状態ではCVT内部で油が循環するため、デフ室の油量コントロールが難しいが、CVT7 W/Rは、デフ室の油量を徹底的に低減するために、下記3つの視点で対策を検討しCAEにより運転状態のCVT全体の内部循環流の挙動解析を行った。

- (1) デフ室の容積の低減
- (2) デフ室への流入油量の低減
- (3) デフ室からの流出油量の増加

具体的には、トランスミッション内部全体をモデル化し、内部部品同士の隙間に発生する油の流れを過渡現象も含め、かつ、気液混相流状況も加味して計算できるようにした。これにより、デフ室からミッション内部の他室に排出される油の挙動、および、壁流等により他室からデフ室に戻る循環流の挙動が正確に予測できる手法を開発できた。

## 4. デフ部攪拌フリクション低減方策

### 4.1. デフ室形状変更による容積低減

CVT運転状態はファイナルギアが回転することによりデフ室に溜まった油をかき上げるため、ファイナルギア周辺の油量が少ないほど油面を早く下げることができる。これによりファイナルギアが油と接触する面積を低減でき、デフの攪拌フリクションを低減できる。

In developing the CVT7 W/R, specifications for reducing the amount of fluid in the differential chamber were examined by conducting fluid flow analyses under operating conditions. The aim was to reduce churning friction by just changing the specifications of the differential chamber and auxiliary gearbox case geometries without adding any baffle plates or other parts so as to ensure cost competitiveness.

### 3. Issues

The key point for reducing churning friction in the differential chamber was to decrease the quantity of fluid and increase the gas phase region in the chamber under transient conditions. Because the fluid circulates internally in a CVT in a transient operating state, it is difficult to control the quantity of fluid in the differential chamber. The behavior of the fluid circulating throughout the entire CVT in a transient state was analyzed by CAE to investigate measures for thoroughly reducing the quantity of fluid in the differential chamber from the following three perspectives.

- (1) Reducing the volume of the differential chamber
- (2) Reducing the quantity of fluid flowing into the chamber
- (3) Increasing the quantity of fluid flowing out of the chamber

Specifically, the entire interior of the transmission was modeled to enable calculations of the flow of fluid occurring between the clearances of interior parts, including transient phenomena, and also taking into account the condition of the gas-liquid mixed flow. As a result, a method was developed for accurately predicting the behavior of the fluid evacuated from the differential chamber to other chambers in the transmission and the behavior of the fluid circulated back from other chambers to the differential chamber such as by wall flow.

## 4. Measures for Reducing Churning Friction in the Differential Chamber

### 4.1 Reduction of differential chamber volume by changing its shape

Because the rotation of the final gear stirs up fluid collected in the differential chamber in a CVT operating state, the less fluid there is around the final gear, the faster the fluid level can be lowered. As a result, the area of contact between the final gear and the fluid can be reduced, making it possible to lower churning friction in the differential chamber.

従来用いていた手法としては、ファイナルギア周辺をバッフルプレートで囲むことにより別室を作り、かき上げられた油がバッフルプレートの外側に落ちる構造とすることで、運転状態のファイナルギア周辺の油量を低減していた(Fig.2)。しかしながら、上記解決法を採用した場合は、部品追加によるコストアップやレイアウトへの影響が大きな課題となる。

CVT7 W/Rで、部品追加無しでバッフルプレートと同様の効果を得ることを狙い、ケース形状を変更することでファイナルギア周辺の油量を低減することを可能とした(Fig.3)。

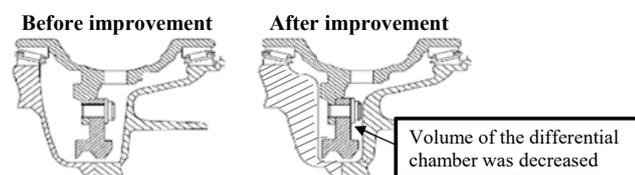


Fig. 3 Shape of differential chamber

Fig.4に流体解析に拠るデフ室形状変更有無での油かき上げ量の違いを示す。ケース形状変更により狙い通り油かき上げ量が低減することが確認できた。

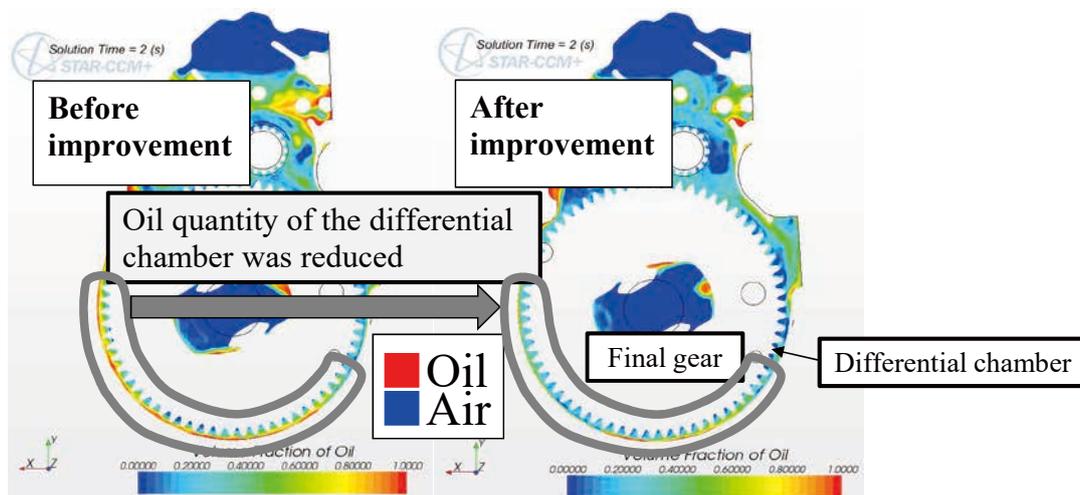


Fig. 4 Results of CAE analysis of fluid flow

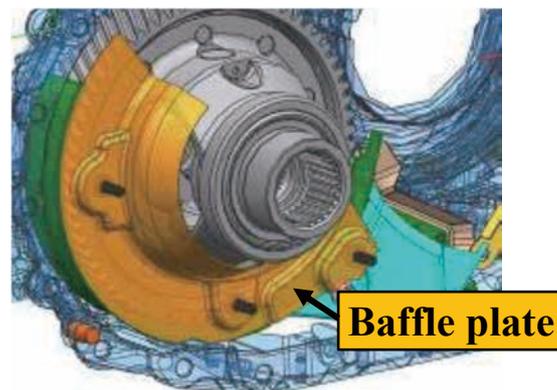


Fig. 2 Structure of baffle plate

The method used heretofore was to build a separate chamber by enclosing the area around the final gear with a baffle plate (Fig. 2). This formed a structure such that the fluid stirred up by the final gear fell on the outside of the baffle plate, thereby reducing the quantity of fluid around the final gear in an operating state.(1) However, the adoption of this approach involved the issues of increased cost due to the additional parts and substantial impact on the layout.

The aim set for the CVT7 W/R was to obtain the same effect as with the baffle plate but without applying any additional parts. That was accomplished by changing the shape of the differential chamber, which enabled the quantity of fluid around the final gear to be reduced (Fig. 3).

Figure 4 presents the results of a CAE fluid flow analysis showing the difference in the quantity of fluid stirred up before and after improvement of the differential chamber shape. The results confirm that changing the chamber shape reduced the quantity of fluid stirred up as was intended.

#### 4.2. 副変速部ケース形状変更による流入油量低減

デフ室の油量を低減させる方策として、デフ室への流入油量を低減させる案がある。運転状態の油は潤滑油としての機能も満たす必要があるため、CVT内部を循環している。改良前はデフ室の上部にある副変速部の潤滑油がデフ室に流入し易い構造となっていた。

CVT7 W/Rは、副変速部の油がデフ室ではなく、コントロールバルブ室に流れるように、ケース形状を改良した (Fig.5).



Fig. 5 Optimized shape of auxiliary gearbox case

#### 4.3. 連通穴形状変更による流出油量増加

デフ室の油量を低減させる方策として、デフ室からの油流出量を増加させる案がある。運転状態ではデフ室にある油がファイナルギアにより攪拌されるが、かき上げられ飛散した油を流出させる構造が無いとデフ室内に油が残留する。

改良前の運転状態の油の流れを解析した結果、デフ室とコントロールバルブ室をつなぐ上側の連通穴より飛散した油の一部が流出し、下側の連通穴より油がデフ室に流入している結果が得られた (Fig.6).

4.2 Reduction of fluid flowing into differential chamber by changing shape of case near auxiliary gearbox case

One measure proposed for reducing the quantity of fluid in the differential chamber was to decrease the amount of fluid flowing into the chamber. In an operating state, the fluid is circulated inside the CVT because it must also fulfill its function as a lubricant. Before the improvement, the fluid lubricating the auxiliary gearbox positioned above the differential chamber tended to flow into the chamber owing to this structure.

For the CVT7 W/R, the shape of the auxiliary gearbox case was improved so that fluid inside the gearbox flows into the control valve chamber instead of into the differential chamber (Fig. 5).

4.3 Reduction of fluid flowing into differential chamber by changing the connecting hole shape

Another measure proposed for reducing the quantity of fluid in the differential chamber was to increase the amount of fluid flowing out of the chamber. Fluid in the differential chamber is churned by the final gear in an operating state, but fluid that is stirred up and splashed around has to remain in the chamber unless there is a structure enabling it to flow out.

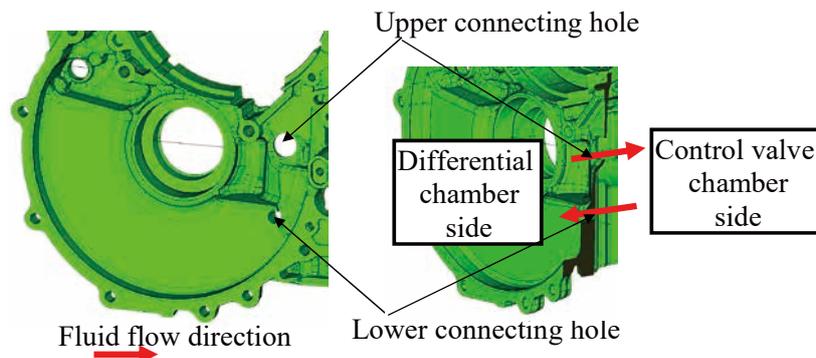


Fig. 6 Results of CAE analysis of fluid flow direction at connecting holes between the differential chamber and the control valve chamber

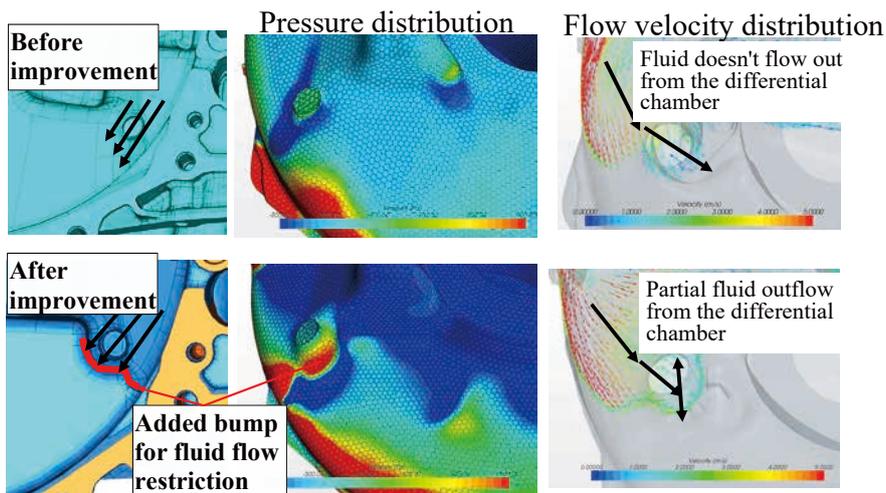


Fig. 7 Results of CAE analysis of fluid flow

CVT7 W/Rでは連通穴から流出する油量を増加させる構造を検討した。上側の連通穴は油を積極的に流出させるために、飛散した油が連通穴を通過するように壁流も考慮して連通穴周辺の形状、および連通穴の位置、形状を最適化した。

下側の連通穴は改善前の形状ではファイナルギアが回転することによるポンプ効果作用でデフ室内に負圧が発生し、油をデフ室へ吸入していた。そこで、連通穴にザグリを入れることによりファイナルギアと連通穴の距離を拡大しポンプ効果を低減でき、かつ、ザグリの段差に回転している油が当たることにより油の流れが変わりデフ室から油を流出できる効果があることが解析により分かった(Fig.7)。

対策仕様での運転状態のトランスミッション全体の油の流れを解析した結果をFig.8に示す。デフ室から油が流出し気相状態となる。

以上の方策により、デフの搅拌フリクションを改善前に対して40%低減することが可能となった(Fig.9)。

The results of a fluid flow analysis in an operating state before the improvement revealed that some of the splashed fluid flowed out through the upper connecting hole linking the differential chamber and the control valve chamber. However, fluid flowed into the differential chamber through the lower connecting hole (Fig. 6).

For the CVT7 W/R, a study was made of a connecting hole shape that would increase the quantity of fluid flowing out of the differential chamber. The shape around the upper connecting hole and the connecting hole shape and position were optimized, taking into account wall flow as well, so that splashing fluid would pass through the hole. These changes were made to actively promote the outflow of fluid through the upper connecting hole.

The flow analysis results showed that fluid was sucked into the differential chamber through the lower connecting hole before the shape was improved. The rotation of the final gear created a pumping effect, producing a vacuum in the chamber that sucked the fluid in. Therefore, spot facing was applied to the lower connecting hole to increase the

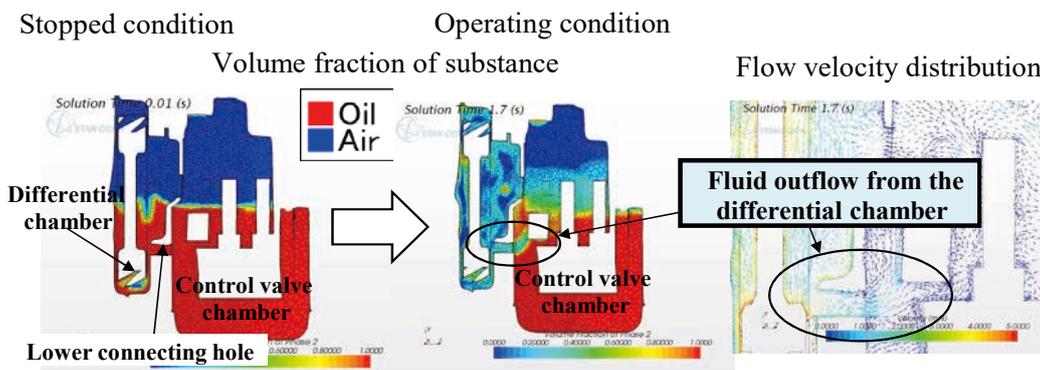


Fig. 8 Results of CAE analysis of fluid flow throughout the interior of CVT7 W/R

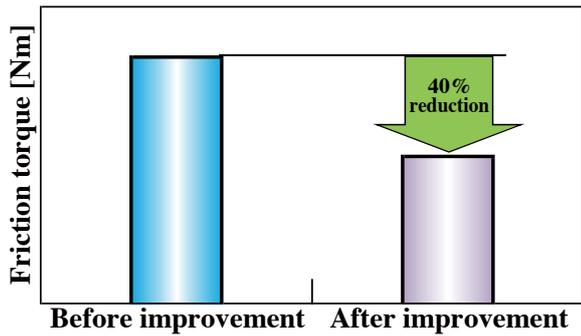


Fig. 9 Measured churning friction in the differential chamber

## 5. おわりに

CVT7 W/Rでは、トランスミッション全体の内部循環流を、過渡現象、および気液混相流も考慮したシミュレーションで予測できるようにし、その活用によりデフ攪拌フリクション低減仕様を開発することができた。

シミュレーション解析にてパラメータ設計ができた功績は大きく、これにより短期間で商品開発を終えることができ、この種の課題を解決するために多用されるバッフルプレートなどの部品追加も回避することが可能となった。本手法の開発により今までは実機検証の繰り返しで仕様決めをしていた案件をCAE活用による机上予測設計とすることが可能となった。

最後に本稿を記載するにあたり、ご支援いただいた関係部署の方々へ感謝の意を表したい。

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distance between it and the final gear so as to reduce the pumping effect. The flow analysis results also revealed that the direction of the fluid flow changed when the swirling fluid struck the level difference formed by the spot facing. That had the effect of enabling the fluid to flow out of the differential chamber (Fig. 7).

Figure 8 presents the results of a CAE analysis of the fluid flow in an operating condition throughout the entire interior of the CVT7 W/R incorporating the improved specifications. The results indicate that fluid flows out of the chamber to create an gas phase state.

The adoption of the foregoing measures reduced churning friction in the differential chamber by 40% compared with the friction level before the improvement (Fig. 9).

## 5. Conclusion

A simulation method was developed for predicting fluid flow throughout the entire interior of a CVT under transient operating conditions and also taking into account gas-liquid mixed flow. The use of this method made it possible to develop specifications for reducing churning friction in the differential chamber of the CVT7 W/R.

Simulation analysis was notably effective in executing the parameter design, enabling the development of this new CVT to be completed in a shorter period of time. It also made it possible to avoid adding other parts such as baffle plates that are often used to solve this type of issue. The newly developed method described here now makes it possible to utilize CAE to execute predictive designs theoretically for proposed specifications, which heretofore had to be determined on the basis of repeated verification experiments conducted with a test transmission.

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# トルクコンバータ発進スリップ制御の小型車への適用

The Application of Start-off Slip Control to a CVT for Small Cars

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抄録 本稿では、市場調査結果から課題化した発進時のエンジン(以下Eng)回転の空吹け量を抑制するために、小型車用CVTの発進スリップ適用について説明する。さらに、ロックアップ(以下L/U)ミートポイント学習を改良した新学習制御の開発と、これに対応するトルクコンバータ(以下T/C)開発によって、精度の良いミートポイント学習が可能となった。実験結果より、本開発が有用であることを示す。以下に本開発の詳細を説明する。

**Summary** This article explains the application of start-off slip control to a CVT for small cars to suppress the amount of engine speed flare at the time of vehicle launch, which was an issue revealed by the results of a market study. In addition, a new learning control was developed that provides improved learning of the lockup clutch meeting point. Together with a newly developed torque converter matching this new learning control, it is now possible to learn the clutch meeting point with greater accuracy. Experimental results have confirmed the effectiveness of these new technologies, which are explained in detail in the following sections.

## 1. はじめに

## 1. Introduction

新開発CVTの搭載車を中国市場に投入するため、どのような使われ方をするのかの市場調査を実施した。その結果、Eng高回転域をあまり使わず、低回転域での走行頻度が高い市場であることが判明した。そのため、発進直後のEng回転の空吹け感に敏感であり、回転数が高い割に駆動力がないと感じるユーザーが多いことも判明した。

A market study was conducted to investigate how vehicles are typically driven in China in connection with the introduction in that market of a vehicle fitted with a newly developed CVT. The results revealed that the engine is not often operated in the high speed range and that there is a high frequency of driving at low engine speeds in the Chinese market. Consequently, it was found that drivers are sensitive to a feeling of engine speed flares immediately after vehicle launch and that many drivers feel there is a lack of power relative to the high engine speed.

上述より、市場の使われ方を考慮し、運転性の良い車両に仕上げるために、発進時のEng回転の空吹け量を抑制する制御を開発した。

Taking these driving patterns into account, a new control was developed for suppressing the amount of engine speed flare at the time of vehicle launch in order to develop a vehicle providing good driveability.

## 2. 発進スリップ制御

## 2. Start-off Slip Control

発進直後からL/Uを締結し、Eng回転の空吹け量を抑えることで、燃費と運転性を向上させることを目的とする発進スリップ制御が開発された。本技術開発では、制御とT/Cの再設計を行った。

Start-off slip control was developed with the aim of improving fuel economy and driveability by suppressing the amount of engine speed flare through lockup clutch engagement right after the vehicle is launched. In developing this technology, the control system and the torque converter were redesigned.

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制御は、「初期圧制御」と「締結制御」の2構成であり、前者は、ユニット個体バラツキを吸収するため、クラッチの締結ポイントを学習し(ミートポイント学習)、これを締結初期圧とする(初期圧出力)。後者は、初期圧制御を前提とし、目標とするEng回転プロフィールでのL/U締結を実現する(L/U伝達トルクコントロール)。制御概要をFig. 1に示す。

発進スリップ制御は、低車速域からL/Uクラッチをスリップ状態にするため、発熱が大きくなる。そのため、T/Cには、耐熱性が高い摩擦材を用いることとした。

### 3. 発進スリップ制御の小型車用CVTへの適用

小型車用CVTに発進スリップ制御を適用することで、Eng回転の空吹き量を抑制する。さらに、ミートポイント学習を改良したStart Meet Point(以下SMP)学習を開発することによって、L/Uクラッチの締結開始点を安定的に学習可能とし、この学習値を初期圧出力に反映することで目標とするEng回転プロフィールでのL/U締結を実現した。

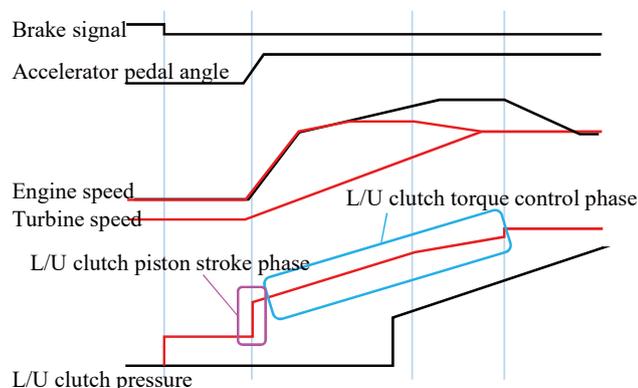


Fig. 1 Start-off slip control

### 4. SMP学習制御

本学習制御は、L/Uクラッチが受け持つトルク(以下、L/Uトルク)を推定し、締結過渡中にクラッチがタッチした瞬間の変化を捉えることで、L/Uミートポイント圧の学習を行う。本学習には、以下2つの利点(A, B)がある。

- A. 学習のために特殊な動かし方をしないため、通常の走行の中で学習が可能である。
- B. 学習値を覚えるシーンと使うシーンが同じであるため、学習精度が高い。

The control system consists of two procedures—initial pressure control and clutch engagement control. The former procedure learns the clutch engagement point (engagement point learning) in order to absorb characteristic variability of transmission. This point is treated as the initial engagement pressure (initial pressure output). The latter procedure achieves lockup clutch engagement at the targeted engine speed profile premised on initial pressure control. This involves controlling the torque transmitted by the lockup clutch. An outline of start-off slip control is shown in Fig. 1.

Because start-off slip control allows the lockup clutch to slip in the low vehicle speed range, the amount of heat generated increases. For that reason, friction material having higher heat resistance was adopted for the torque converter.

### 3. Application of Start-off Slip Control to a CVT for Small Cars

Incorporating start-off slip control in a CVT for small cars is effective in suppressing the amount of engine speed flare. In addition, an improved procedure was developed for leaning the “start of meeting point” (SMP), which is a further improvement on engagement point learning. This procedure makes it possible to stably learn the starting point of lockup clutch engagement. The learned value is reflected in the initial pressure output to accomplish lockup clutch engagement at the targeted engine speed profile.

### 4. SMP Learning Control

This learning control estimates the torque transmitted by the lockup clutch and detects the change in torque at the moment the clutch plates touch in the transition to engagement. In this way, it learns the meeting point pressure of the lockup clutch. Learning the pressure provides the following two benefits.

- A: Learning is possible during ordinary driving because it does not involve any special movement of the clutch.
- B: Learning accuracy is high because the driving situations in which the pressure value is learned and used are the same.

The learning control procedure is explained here. First, the lockup clutch torque is estimated. The point at which the lockup clutch begins to engage is detected from the change in the estimated torque value. The lockup clutch pressure command at that time is regarded as the detected meeting point pressure. Next, the starting point of engagement is estimated from the lockup clutch torque characteristic relative to the clutch pressure command, and the estimated pressure

本学習制御の手順を説明する。まず、L/Uトルクを推定する。L/Uクラッチが締結し始めた点を、L/Uトルク推定値の変化から検出し、このときのL/U指令圧をミートポイント検知圧とする。次に、L/U指令圧に対するL/Uトルク特性から締結開始点を推定し、ミートポイント推定圧を求める。2つのミートポイント圧の導出結果を比較検証することにより、検知圧の確からしさを判定し、妥当であると判断ができれば、学習更新を行う。

本制御の詳細について、以下に示す。

#### 4.1. L/Uトルク推定

本学習の基礎となるL/Uトルク推定値の推定手法を示す。算出は、以下式による。

$$T_{lu} = (T/C \text{ 入力トルク}) - (\text{流体トルク}) \\ = (T_e - T_{op}) - (\tau \times N_e^2) \quad \dots (1)$$

$T_e$  : Engトルク[Nm]  
 $T_{op}$  : O/Pフリクショントルク[Nm]  
 $\tau$  : T/C容量係数[Nm/rpm<sup>2</sup>]  
 $N_e$  : Eng回転[rpm]

T/Cへの入力トルクからT/Cの流体部分が受け持つトルク(流体トルク)を差し引くことで、L/Uトルクを推定する。

#### 4.2. ミートポイント検知

L/Uが締結していないとき、L/Uトルクは0[Nm]である。ミートポイントを検知するためには、L/Uトルクが立ち上がる瞬間を検出すれば良い。ここでは、 $T_{lu}$ に対して、エッジ検出フィルタを適用することで、ミートポイントを検出する。また、このときのL/U指令圧をミートポイント検知圧とする。

#### 4.3. 誤学習回避対策

誤ったミートポイントを検知し、その際のミートポイント圧を誤学習した場合、狙いとする締結プロフィールが実現できない。ミートポイント圧を低い側で誤学習した場合は、Eng回転が吹ける方向になり、高い側で誤学習した場合は、締結初期圧過大による許容を上回るクラッチ締結時トルク変動の懸念がある。そのため、ミートポイントの検知ばらつきに対して高い学習精度が要求される。

本学習は、 $T_{lu}$ を基礎とした検出手法であるため、 $T_{lu}$ の推定精度が、学習精度に直結する。そのため、 $T_{lu}$ がばらつく条件を抽出し、誤学習の懸念がある場面(T/C入力トルクの急変等)は、学習値の更新を行わない。

at the meeting point is calculated. A comparative verification is made of the two derived meeting point pressures, and the probability of the detected pressure is judged. If the value is judged to be valid, the learned value is updated. A detailed explanation of this learning control is given below.

#### 4.1 Estimation of lockup clutch torque

This section explains the method of calculating the estimated lockup clutch torque value  $T_{lu}$ , which is the basis of this learning control. The calculation is done using the following equation.

$$T_{lu} = (T/C \text{ input torque}) - (\text{fluid torque}) \\ = (T_e - T_{op}) - (\tau \times N_e^2) \quad (1)$$

$T_e$ : engine torque [Nm]

$T_{op}$ : oil pump friction torque [Nm]

$\tau$ : torque converter capacity coefficient [Nm/rpm<sup>2</sup>]

$N_e$ : engine speed [rpm]

Lockup clutch torque is estimated by subtracting the torque transmitted by the fluid section of the torque converter (fluid torque) from the input torque of the torque converter.

#### 4.2 Meeting point detection

Lockup clutch torque is zero Nm when the clutch is not engaged. The lockup clutch meeting point can be detected by detecting the moment when the lockup clutch torque begins to rise. In this learning control, the meeting point is detected by applying an edge detection filter to  $T_{lu}$ . The lockup clutch pressure command at that time is regarded as the detected meeting point pressure.

#### 4.3 Measure for avoiding erroneous learning

The targeted engagement profile cannot be obtained if the meeting point is mistakenly detected and the meeting point pressure at that time is erroneously learned. If the meeting point pressure is erroneously learned on the low side, the engine speed may flare, and if erroneously learned on the high side, torque fluctuation at the time of clutch engagement may exceed the allowable tolerance owing to excessive initial engagement pressure. To avoid these concerns, it is necessary to have high learning accuracy for the variation in meeting point detection.

Because the detection method in this learning control is based on  $T_{lu}$ , the estimation accuracy of  $T_{lu}$  is directly linked to learning accuracy. Therefore, conditions causing  $T_{lu}$  to vary were identified, and the learned value is not updated in situations where there is concern that erroneous learning might occur, such as in the case of a sharp change in the input torque of the torque converter.

#### 4.4. ミートポイント推定による学習更新妥当性検証

ここでは、ミートポイント圧を推定する手法について説明する。ここで算出する推定圧と4.2.で説明した検知圧の2手法によるミートポイント圧の導出結果を比較検証し、妥当性を判断する。これにより、学習精度の向上を図ることができる。

ミートポイント推定は、L/U差圧に対するL/Uトルクがリニアな関係であることを用いる。これを表す式を以下に示し、L/Uトルクの構成要素をFig.2で説明する。

$$L/U \text{トルク} = \mu \times Plu \times A \times r \quad \dots (2)$$

- $\mu$  : 摩擦係数[-]
- $Plu$  : L/U差圧[MPa]
- $A$  : ピストン受圧面積[mm<sup>2</sup>]
- $r$  : 有効半径[mm]

この線形性を用いて、ミートポイント圧を推定する。

上記結果より、検知圧と推定圧の差分値がある幅の中に収まっていれば正しく検知、推定できたと判断し、所定量を更新する。

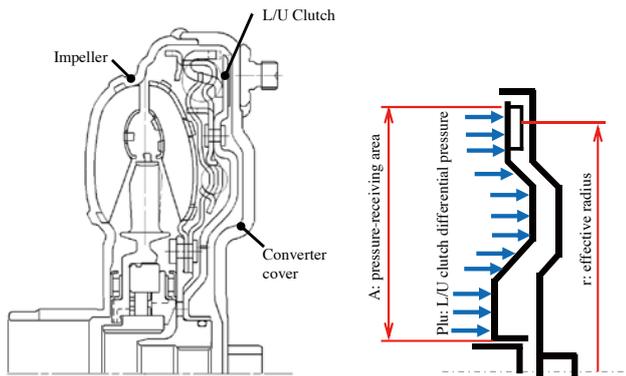


Fig. 2 Explanation of lockup clutch torque components

#### 4.5. SMP学習による効果

学習制御の織り込み前後を比較し、効果について説明する。比較結果をFig.3に示す。Fig.3より、未学習(Not learned)に対して、学習済み(Learned)ではEng回転の空吹け量を抑制できていることがわかり、有用であることが確認できた。

### 5. SMP学習精度を向上するためのT/C開発

SMP学習を精度良く、安定的に行うため、L/Uトルクバラツキを小さくするT/Cを開発する必要があった。式(2)より、L/Uトルクの影響因子として、摩擦係数、L/U差圧、ピストン受圧面積、有効半径が挙げられる。

#### 4.4 Verification of validity of updating learned value based on meeting point estimation

This section explains the method of estimating the meeting point pressure. Two methods are involved in deriving the meeting point pressure: the estimated pressure is calculated as explained below, and the pressure is detected as explained in section 4.2 above. A comparative verification is made of the two derived values and their validity is judged. This procedure works to improve learning accuracy.

The meeting point is estimated by using the linear relationship of the lockup clutch torque to the clutch differential pressure. The calculation is done using the equation shown below. The constituent elements of the lockup clutch torque are explained in Fig. 2.

$$\text{Lockup clutch torque} = \mu \times Plu \times A \times r \quad (2)$$

- $\mu$ : friction coefficient [-]
- $Plu$ : lockup clutch differential pressure [MPa]
- $A$ : pressure-receiving area of piston [mm<sup>2</sup>]
- $r$ : effective radius [mm]

The meeting point pressure is estimated using this linear relationship.

Based on the results obtained, if the differential value of the detected pressure and estimated pressure is within a certain range, it is judged that the detection and estimation were done correctly, and the specified value is updated.

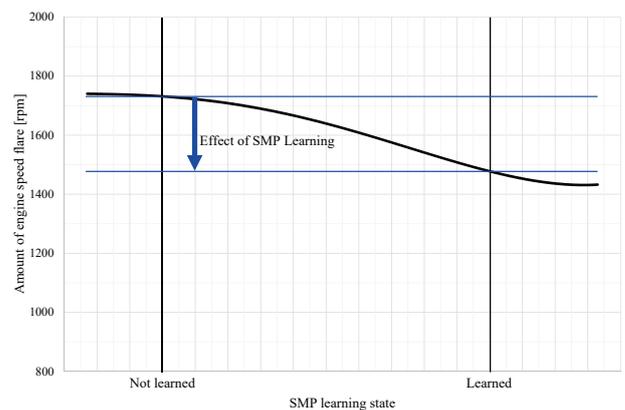


Fig. 3 Effect of SMP Learning

#### 4.5 Effect of SMP Learning

The effect of SMP learning is explained here by comparing the results obtained before and after learning control was adopted. Figure 3 shows a comparison of the waveforms. The engine speed waveform with SMP learning (After) shows that the amount of engine speed flare was suppressed compared with the waveform without SMP learning (Before). This confirmed the effectiveness of SMP learning.

本開発では、影響度の大きい摩擦係数および有効半径のバラツキを小さくする方向で再設計を行った。このとき、再設計判断に用いたFTA (Fault Tree Analysis) 結果をFig.4に示す。

摩擦係数は摩擦材の密度の影響を受けるため、摩擦材接着時の圧縮をストローク制御ではなく、推力制御にすることにより、完成品の密度バラツキを小さくすることに成功した。これにより、摩擦係数バラツキは従来材に比べて70%の改善ができた (Fig.5)。

また、有効半径バラツキを小さくするための方策として、製品剛性の高い部分でのチャック、ひずみを見込んだ治具の設計など、作りの工夫を実施した。これにより、有効半径のバラツキは約25%低下できた (Fig.6)。

以上より摩擦係数バラツキを約70%、有効半径バラツキを約25%低減し、L/Uトルクとして約75%のバラツキ低減ができ、SMP学習制御の安定化に貢献できた。

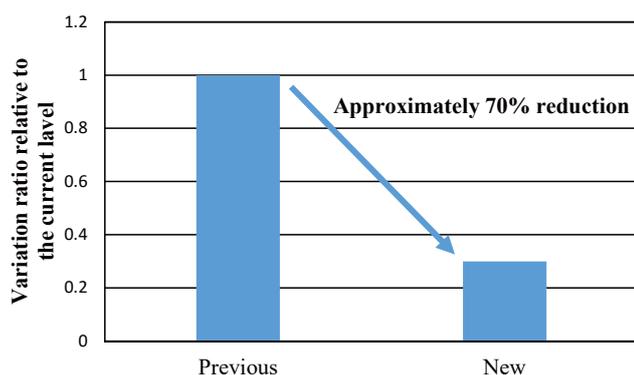


Fig. 5 Comparison of friction coefficient

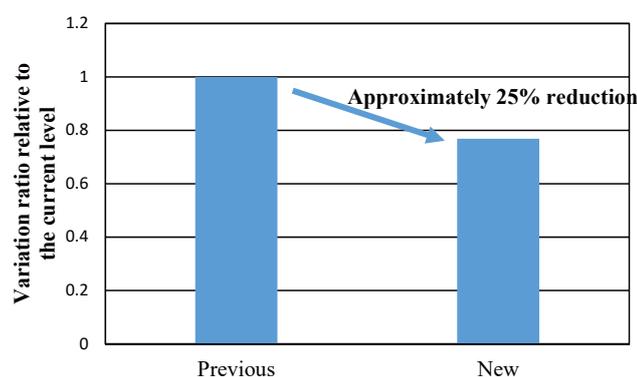


Fig. 6 Comparison of effective radius

## 6. 結果

発進スリップ制御および改良T/Cの小型車用CVTへの適用前後の実車波形をFig.7に示す。この結果より、

## 5. Development of a Torque Converter for Improving SMP Learning Accuracy

In order to perform SMP learning accurately and stably, it was necessary to develop a torque converter capable of reducing lockup clutch torque variation. Equation (2) shows that the factors affecting lockup clutch torque are the friction coefficient, lockup clutch differential pressure, pressure-receiving area of the piston and the effective radius. In this development work, the torque converter was redesigned so as to reduce the variation in the friction coefficient and the effective radius, which have a large impact on accuracy. Figure 4 presents the results of a fault tree analysis (FTA) that was used in judging the redesign effectiveness.

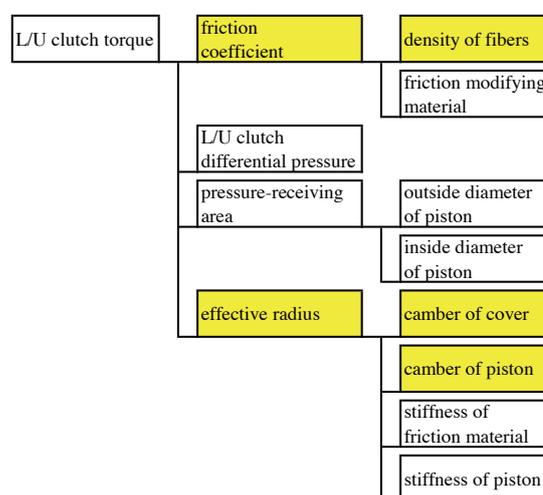


Fig. 4 FTA

The friction coefficient is influenced by the density of the friction material. At the time the friction material was bonded, compression was based on thrust control rather than stroke control, which successfully reduced variation in the density of the finished product. As a result, friction coefficient variation was reduced by approximately 70% compared with the previous material (Fig. 5).

The measures taken to reduce variation in the effective radius involved innovation in the manufacturing method, such as designing a jig that factored in the chucking and straining of the high stiffness area of the material. As a result, variation in the effective radius was reduced by approximately 25% compared with the previous material (Fig. 6).

These measures that reduced the friction coefficient variation by approximately 75% and the effective radius variation by approximately 25% contributed significantly to stabilizing SMP learning control by reducing lockup clutch torque variation by approximately 75%.

同一アクセル開度において、Before(発進スリップ未適用車)波形に対して、After(発進スリップ適用車)波形の方がEng回転の空吹け量を抑制できており、Eng回転数の大きな落ち込みもなくL/U締結できていることがわかる。

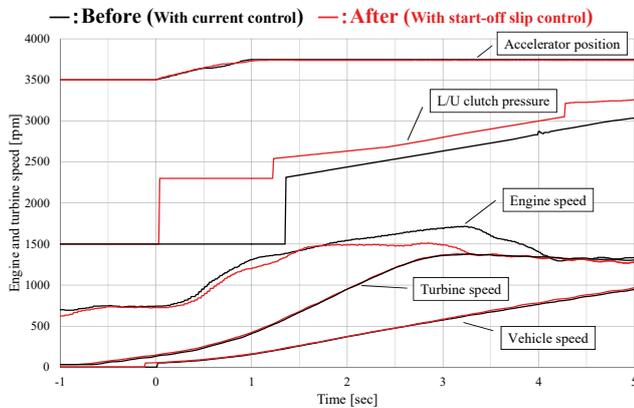


Fig. 7 Experimental results

## 7. 結論

本稿では、市場調査結果から発進時のEng回転の空吹け量を抑制するために、小型車用CVTの発進スリップ適用について説明した。さらに、SMP学習制御とこれに対応するT/C開発によって、精度の良いミートポイント学習を可能とした。実験結果より、発進直後のEng回転の空吹け量を抑えることができ、有用な制御とT/Cを開発できたことが確認できた。

## 8. おわりに

本T/Cの開発にあたりご協力いただいたユニプレス株式会社の皆様、株式会社エフ・シー・シーの皆様をはじめ、多大なる協力をいただいた関係者の方々に深く感謝の意を表す。

## 6. Results

Figure 7 presents the test vehicle waveforms obtained experimentally before and after start-off slip control and the improved torque converter were applied to a CVT for small cars. At the same accelerator pedal position, the engine speed waveform of the vehicle with start-off slip control (After) shows that the amount of engine speed flare was suppressed compared with the waveform of the vehicle without start-off slip control (Before). The results obtained with start-off slip control indicate that the lockup clutch was engaged without any large drop in engine speed.

## 7. Conclusion

This article has explained the application of start-off slip control to a CVT for small cars to suppress the amount of engine speed flare at the time of vehicle launch, an issue that was revealed by the results of a market study. In addition, the application of SMP learning control and a newly developed torque converter compatible with this control procedure have made it possible to learn the meeting point of the lockup clutch with good accuracy. Experimental results showed that the amount of engine speed flare right after vehicle launch was suppressed with start-off slip control and the new torque converter, thereby confirming their effectiveness.

## 8. Acknowledgments

The authors would like to express their deep gratitude to everyone involved for the invaluable cooperation received for the development of the new torque converter, especially all the people concerned at Unipres Corporation and F.C.C. Co., Ltd.

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# 無段変速機の歯当たり予測のための新解析手法の開発

Development of a New Simulation Method for Predicting Tooth Contact in a CVT

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**抄 録** Jatco CVT7 W/R(以下, CVT7 W/Rと称す)は、燃費、運転性能を向上し、ユニット内のトルク伝達機構である歯車においても、音振性能向上を実現している。

本稿では、歯車の音振性能や歯車のサイズを決める歯元応力、歯面強度などのベースとなっている歯当りを予測する手法を開発したので、その内容について紹介する。

**Summary** The Jatco CVT7 W/R improves vehicle fuel economy and driveability while also reducing the noise and vibration of the gears that form the torque transmission mechanism inside this CVT. This article describes the details of a newly developed method for predicting tooth contact on the basis of tooth root stress and tooth surface strength, which determine the gear size and gear noise and vibration performance.

## 1. はじめに

歯車の音振性能、耐久信頼性は、トランスミッションの歯車や周辺部品の変形による歯当りの影響を受けるかみ合い伝達誤差に左右される。そのため、耐久信頼性の高い歯車を設計するためには、正確な歯当りの予測が必要になる。

本稿では、CVT7 W/Rの歯車開発において、音振性能と高い耐久信頼性を両立するために、無段変速機(CVT)の正確な歯当りを予測するための手法を開発したので、その内容について紹介する。

## 1. Introduction

Gear noise, vibration, durability and reliability are governed by the transmission error of meshing gears, which is influenced by tooth contact caused by deformation of the gears or peripheral parts. For that reason, it is necessary to predict tooth contact accurately in order to design gears with high levels of durability and reliability.

This article describes the details of a newly developed method for accurately predicting tooth contact in a CVT. This method was developed in the course of developing the gears of the CVT7 W/R in order to obtain excellent noise and vibration performance combined with high durability and reliability.

## 2. 開発の狙い

本研究の対象歯車対は、2.0~2.5Lエンジンクラスの車両モデルへ適用されている当社の既販CVTであるJF011Eの1次減速歯車対である。Fig.1にCVT断面図とその対象歯車対を示す。

従来の剛性解析による歯当たり予測結果は、実験による歯当りの結果と乖離がある。Fig.2にアウトプット歯車対での解析による歯当りの結果と実験結果を示す。実験に対して、解析値は、約50%の変形量となっていることがわかる。

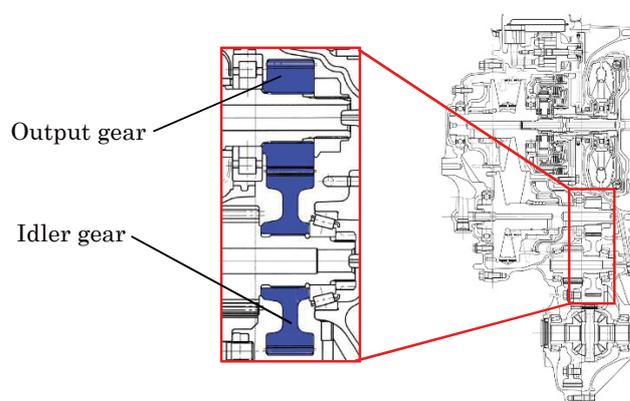


Fig. 1 Cross-sectional view of Jatco JF011E and gears of interest

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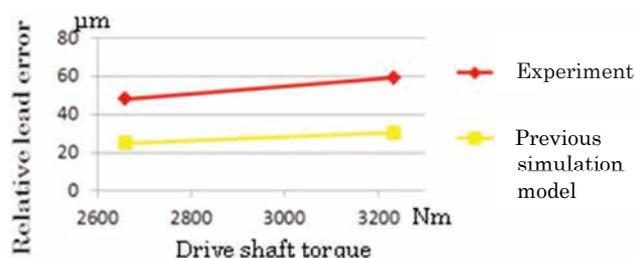


Fig. 2 Relationship between transmission error and drive shaft torque

自動変速機や手動変速機と比較して、CVT用のアウトプット歯車対は、高い油圧、ベルト張力、歯車のかみ合い反力により、軸にかかる荷重が複雑である特徴がある。その構成を、Fig.3に示す。荷重が大きく、他軸からの影響を受け、ユニット内に設置されているベアリングのがたの影響も受ける。

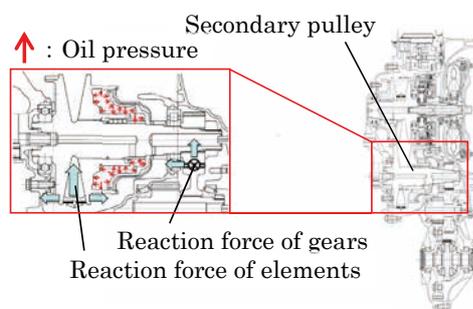


Fig. 3 Forces acting on the shaft

従来の剛性解析モデルでは、前記の複雑な荷重、がたの影響を考慮できていないため、精度良く予測できないと考え、解析手法の見直しを行った。

その中で特に効果の大きかった改良を紹介する。

- ①油圧作動時のプーリとベルトの挙動観察結果を用いたFEMモデルの同定
- ②ボールベアリングの挙動の観察結果を用いたFEMモデルの同定

### 3. 改良技術とその効果

#### 3.1. プーリとベルトの挙動解析

プーリとベルトの改良をFig.4に示す。油圧室に油圧と等価な面圧を付与して、油圧を再現できるようにした。次にベルトを構成するエレメントをカップリングにて作成し、リングをシェル要素でモデル化した。プーリとエレメントの接触要素を追加し、実機状態を再現した。

## 2. Development Aim

The gear pair of interest in this study was the primary reduction gear in the Jatco JF011E CVT that is already being used on midsize vehicles fitted with a 2.0-2.5L engine. A cross-sectional view of this CVT is shown in Fig. 1 along with the locations of the gear pair of interest.

The results of a tooth contact prediction based on a conventional stress simulation diverge from the results of tooth contact found experimentally. Figure 2 compares the tooth contact of the output gear pair found by simulation and experimentation. It is seen that the simulated values deviate from the experimental results by approximately 50%.

Compared with an automatic transmission or a manual transmission, the output gear pair of a CVT is characterized by the complex forces acting on the shaft owing to high hydraulic pressure, belt tension and reaction forces of meshing gears. The composition of the forces is shown in Fig. 3. The shaft is influenced by the large forces, effects from other shafts and the play of the bearings provided inside the CVT.

The stiffness simulation model used previously was not able to predict tooth contact accurately presumably because it did not take into account these complex forces and the influence of bearing play. Therefore, the simulation method was revised. Among the improvements made, the following two points are described here because they had an especially large effect on improving prediction accuracy.

- (1) Identification of the FEM simulation model using the observation results for pulley and belt behavior at the time hydraulic pressure is applied
- (2) Identification of the FEM simulation model using observation results for the behavior of the ball bearings

## 3. Technical Improvements and Their Effects

### 3.1 Simulation of pulley and belt behavior

The modeling improvements made for the pulleys and belt are shown in Fig. 4. Surface pressure equivalent to the hydraulic pressure in the pressure chamber was applied, making it possible to reproduce the hydraulic pressure. Next, the elements of the metal push belt were modeled using coupled finite elements and the bands were modeled using shell elements. A finite element was added to represent the contact between the belt and pulleys, thus reproducing the conditions of an actual CVT.

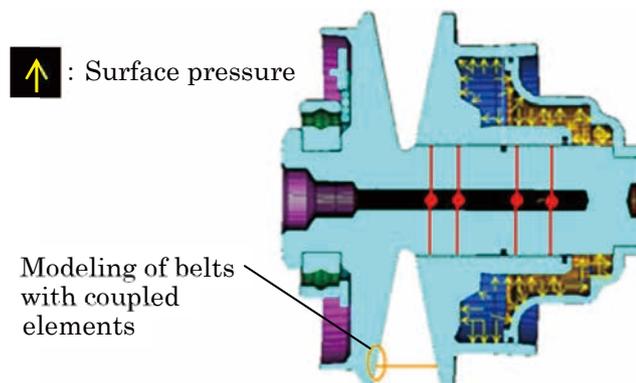


Fig. 4 Modeling improvements

以上の改良による効果を、Fig.5に示す。なお、測定点は、Fig.6に示すようにアウトプットギヤの側面とし、軸方向の変位量を4点測定し歯当りを求めた。改良後の結果は、改良前 $12\mu\text{m}$ と比べて、改良後 $24\mu\text{m}$ と実験の $23\mu\text{m}$ に近づいた。

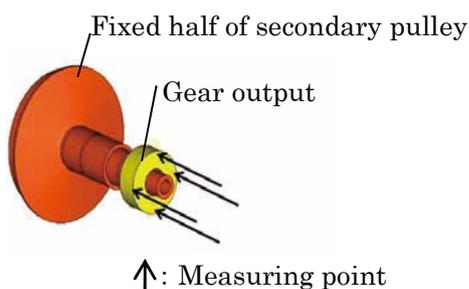


Fig. 6 Measuring point

### 3.2. ボールベアリングの挙動解析

ベアリングについての解析モデルの改良点を、Fig.7に示す。従来の剛性解析モデルのベアリングは圧入状態を再現しておらず、転動面とボールの接触位置については、転動面端にて接触要素を配置している。改良モデルは、外輪はめ合い、内輪がたと内輪はめ合いを追加し、さらに、計算により求めた接触面とボールの接触位置を再現した。接触位置の計算方法としては、外輪を拘束した状態で、内輪にアキシャル荷重、ラジアル荷重を入力し、ヘルツ接触を用い、力の釣合いを解いて、接触角度を求めた。

Fig.8に改良の効果を示す。測定点はFig.9に示すようにアウトプットギヤ側面のアキシャル方向の位置とした。従来のモデルでは、トルク負荷後にプラス側に変位していたが、改良後は実験結果と同じようにマイナス側に変位し、傾向が合うようになった。

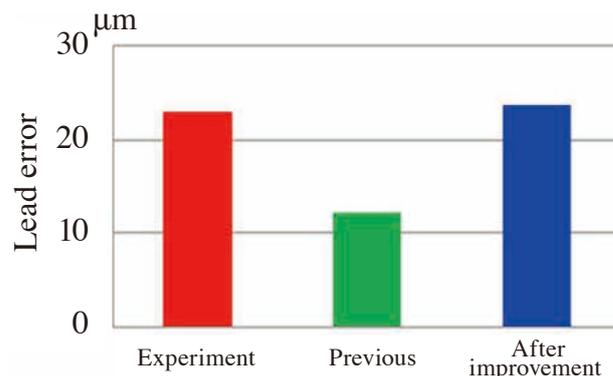


Fig. 5 Effect of improvements

The effect of these improvements is shown in Fig. 5 in comparison with the previous model and the experimental results. As shown in Fig. 6, the amount of deflection at the side face of the output gear was measured in the axial direction at four places to determine tooth contact. As seen in Fig. 5, lead error after the improvements was found to be  $24\mu\text{m}$ , which more closely resembled the experimental value of  $23\mu\text{m}$  than the lead error value of  $12\mu\text{m}$  before the improvements.

### 3.2 Simulation of ball bearing behavior

The improvements made to the simulation model of the bearings are shown in Fig. 7. The previous stress simulation model of the bearings did not reproduce their press-fitted condition. Contact elements were positioned at both ends of the rolling contact surface to reproduce the contact between the raceways and the balls. We also added the outer race fit and inner race play and fit to the improved model. In addition, the improved model also reproduced the calculated contact position between the contact surface and the balls. The contact position was calculated by applying axial and radial forces to the inner race while the outer race was restrained; the contact angle was calculated by solving the force balance using Hertzian contact theory.

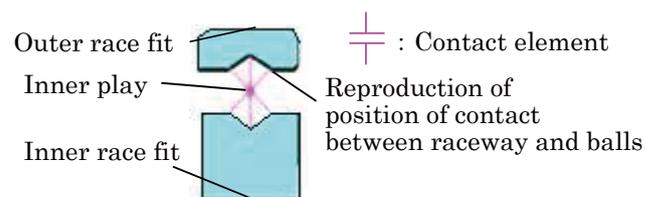


Fig. 7 Bearing model improvements

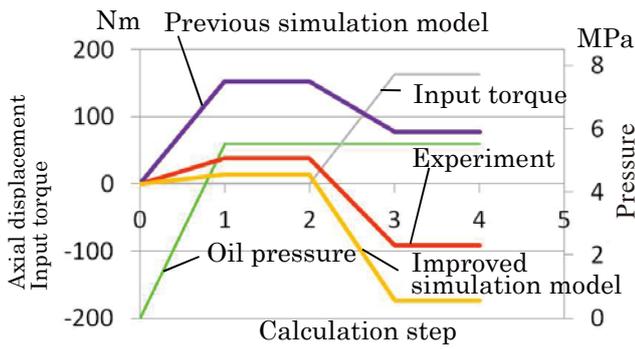


Fig. 8 Displacement of output gear

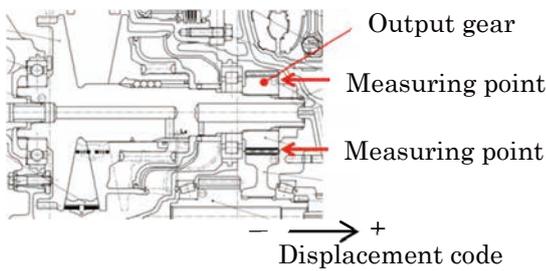


Fig. 9 Measuring points

4. 新解析モデルの予測精度

今回開発した新解析モデルで計算したアウトプット歯車対の歯当たりと実験値の歯当たりを、2つのトルク水準で比較した結果をFig.10に示す。絶対値と傾きが共に、従来の解析モデル(25 $\mu\text{m}$ , 30 $\mu\text{m}$ )に対して大幅に実験値(48 $\mu\text{m}$ , 59 $\mu\text{m}$ )に近づいており、新解析モデル(44 $\mu\text{m}$ , 55 $\mu\text{m}$ )の予測精度の有効性が確認できた。

5. まとめ

CVTの油圧による変形の考慮、およびがたやはめ合いを考慮した新解析手法による歯当たり予測技術により歯車の強度のパラメーターである歯元応力、音振性能のパラメーターであるかみ合い伝達誤差を高精度で予測可能となった。

その結果、CVT7 W/Rの歯車開発において、開発初期段階で高精度な設計が行え、音振性能と高い耐久信頼性を両立することができた。

The effect of the improvements is shown in Fig. 8. The side surface of the output gear in the axial direction was selected for the measuring positions as shown in Fig. 9. With the previous model, it is seen in Fig. 8 that the output gear was displaced in the positive direction when the input torque was applied. With the improved model, it was displaced in the negative direction just as in the experimental results. The simulated tendency thus agreed with the experimental one.

4. Prediction Accuracy of New Simulation Model

The tooth contact calculated with the newly developed simulation model for the output gear pair is compared in Fig. 10 with the experimental tooth contact data at two different torque levels. Both the absolute value and slope (44  $\mu\text{m}$  and 55  $\mu\text{m}$ ) obtained with the new simulation model were much closer to the experimental values (48  $\mu\text{m}$  and 59  $\mu\text{m}$ ) than the values (25  $\mu\text{m}$  and 30  $\mu\text{m}$ ) obtained with the previous simulation model. This confirmed the effective prediction accuracy of the new simulation model.

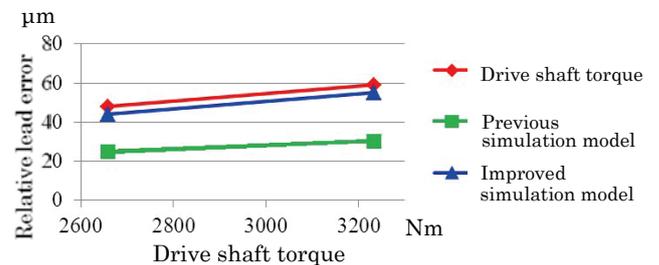


Fig. 10 Relationship between transmission error and drive shaft torque

5. Conclusion

A new simulation method for predicting tooth contact was developed that takes into account deformation due to the hydraulic pressure of the CVT as well as fit and play of the bearings. This prediction technique now makes it possible to predict with high accuracy tooth root stress, which is the parameter for gear strength, and transmission error, which is the parameter for noise and vibration performance.

As a result, highly accurate gear designs were executed in the early stage of developing the gears for the new Jatco CVT7 W/R, making it possible to achieve excellent noise and vibration performance combined with high levels of durability and reliability.

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# ギヤ支持構造改良による遊星ギヤノイズ低減

Performance Design Progress in Reducing Planetary Gear Noise by Redesigning Gear Support Structures

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**抄 録** 遊星歯車機構の支持方法に関しては諸説あり、部品間嵌合部のガタを詰めるなどしてミスアライメントを無くす方法や、逆にガタをある程度持たせて、ギヤ自体の調心作用(セルフセンタリング)を生かす方法がある。今回Jatco CVT7 W/R(以下CVT7 W/Rと呼ぶ)の開発に際したギヤノイズ性能の向上のためにギヤ支持構造改良に取り組み実証・適用したので紹介する。

**Summary** There are various concepts concerning methods of supporting planetary gear sets. One approach is to eliminate misalignment by reducing play in the joints between parts. Conversely, another approach is to allow a certain degree of play to take advantage of the self-centering action of gears. In developing the new Jatco CVT7 W/R, gear support structures were redesigned with the aim of reducing gear noise. This article describes the design measures that were verified and adopted.

## 1. はじめに

## 1. Introduction

Jatco CVT7 Seriesは副変速機とCVTを組み合わせることによって、CVT単独で構成したトランスミッションに比べ、小型車用の小さなエンジンルームに搭載可能なコンパクトなサイズを持ちながら、大幅にトルク伝達容量を増大したり、変速比の幅を拡大させている特長を持っている。

構成要素のうちの副変速機に関して、上記のシステムをコンパクトなレイアウトで実現させるためには、前進時の複数の変速比(CVT7の場合、Low/Highの2段)を実現する機能に加え、後退や停止といった、従来の当社CVTでは単列遊星歯車機構を用いて実現していた機能も併せて持たせることにしたい。そのため、CVT7では複列式であるラビニオ式遊星歯車機構を採用している。

By combining an auxiliary gearbox with a CVT, the JATCO CVT7 Series features markedly increased torque capacity and wider ratio coverage compared with a transmission consisting of a CVT alone. Yet, it still has a compact size that facilitates mounting in the limited engine compartment space of small cars.

The CVT7 adopts a Ravigneaux planetary gear set consisting of a double planetary gear set for the auxiliary gearbox in order to achieve a compact layout for the overall transmission system. That was done because it was desired to provide the functionality for reverse and neutral, which JATCO CVTs have traditionally achieved with a single planetary gear set, in addition to the functionality for providing multiple forward gear ratios (auxiliary gearbox of the CVT7 has two speed ratios, Low and High).

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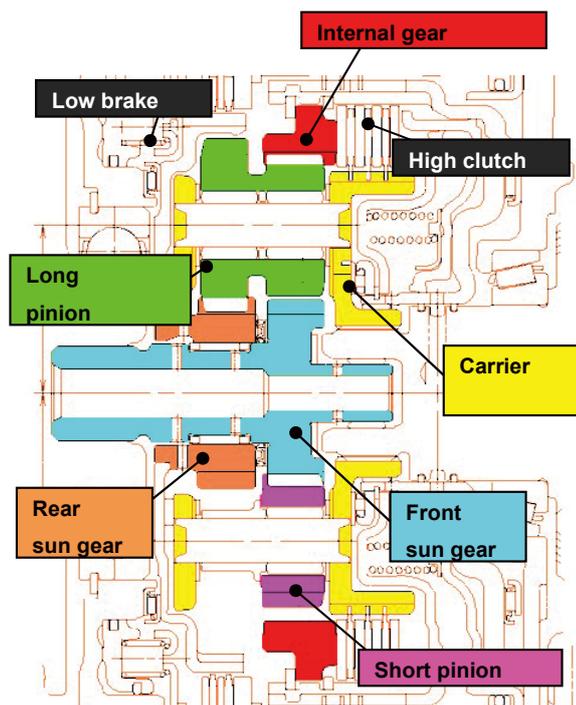


Fig. 1 Ravigneaux planetary gear set

## 2. ラビニオ式遊星ギヤ機構の紹介

ラビニオ式遊星歯車機構について特徴を記す。Fig.1に示すように二種類のサンギヤ(図の右側をフロントサンギヤ・同左側をリアサンギヤと呼ぶ)、軸方向長さが異なる二種類のピニオンギヤ(短い方をショートピニオン・長い方をロングピニオンと呼ぶ)、ピニオンギヤを保持するキャリア、インターナルギヤから構成される。

また、遊星歯車機構は理論上、上記構成要素のうちどれかの回転を止めたり、複数の構成要素同士を直結することで、さまざまな変速比を実現できるが、実際のトランスミッション内では、各々のギヤ・キャリアは湿式多版クラッチやブレーキと嵌合しており、どのクラッチ/ブレーキを締結させるか任意に選択することで、種々の変速比を実現する。例えば、前進時のLow変速比で走行したい場合は、Fig.1のLowブレーキを締結し、リアサンギヤの回転を止める。High変速比で走行したい場合は、ハイクラッチを締結し、直結状態とする。

このように、ラビニオ式遊星歯車機構を用いることで、単列の遊星歯車機構を複数用いた場合に比べ、ギヤとギヤをつなぐ部品などの周辺部品点数が少なくすみ、コンパクトなサイズで多くの変速比を実現できる。

## 2. Overview of Ravigneaux Planetary Gear Set

This section describes the features of the Ravigneaux planetary gear set. As shown in Fig. 1, this gear set consists of two types of sun gears (called the front sun gear on the right side and rear sun gear on the left side), two types of pinion gears of different axial lengths (called the short pinion and long pinion respectively), the carrier that holds the pinion gears, and an internal gear.

Theoretically, a planetary gear set can provide various gear ratios by stopping the rotation of one of the constituent elements or by directly connecting multiple constituent elements together. In an actual transmission, each gear and carrier are joined to a wet multi-plate clutch or brake. Various gear ratios are achieved by freely selecting and engaging the clutches and brakes. For example, when forward travel under the Low gear ratio is desired, the low brake in Fig. 1 is engaged to stop the rotation of the rear sun gear. When forward travel under the High gear ratio is desired, the high clutch is engaged to create a directly engaged condition.

As these examples indicate, using a Ravigneaux planetary gear set enables gears to be coupled together with fewer peripheral parts compared with the use of multiple single planetary gear sets. This makes it possible to provide many gear ratios in a more compact package.

## 3. Issues Occurring in the Operation of Planetary Gear Sets

Gear noise is one issue of concern in the performance design when planetary gear sets are used. The details of gear noise can be found in various references. The source of gear noise lies in transmission error in which there is repeated unevenness because one gear of a meshing gear pair is too advanced or conversely delayed relative to the ideal. Such transmission error is transmitted from the gear support structures to the transmission case, which acts as a speaker. Then, the case vibration is transmitted to the vehicle body via the transmission mounts or other parts and the body acts as a speaker. The resultant noise transferred to the driver's ear position is known as gear noise.

Gear noise occurs at various frequencies, but basically it depends on the meshing cycle. One feature of the planetary gear sets used in the auxiliary gearbox of the CVT7 is that a sideband order is observed as a modulation from the meshing cycle of the gear noise frequency. This is related to the number of teeth in the planetary gear sets, the number

### 3. 遊星歯車機構作動時の課題

遊星歯車機構を使用する場合、性能設計面の一つにギヤノイズがある。ギヤノイズとは、詳細は種々の文献に譲るが、ギヤとギヤがかみ合う際、理想に対し進みすぎたり、逆に遅れたりを繰り返すムラ(かみ合い伝達誤差)を源とし、かみ合い伝達誤差がギヤの支持部分からトランスミッションケースに伝わり、ケースがスピーカーになったり、さらにケースの振動がトランスミッションマウント等を介して車体に伝わり、車体がスピーカーとなったりして、ドライバーの耳元に音として伝わる現象である。

ギヤノイズの発生周波数についてはかみ合い周期によるものを基本として種々あるが、CVT7の副変速機に用いている遊星歯車機構の歯数、ピニオン数、キャリアの使用法(固定せず、常に回転させて用いる)の場合の特徴として、キャリアにピニオンギヤが組み付いているため、キャリア回転時にピニオンギヤが自転だけでなく、公転していることを要因とする、発生周波数のかみ合い周期からの変調が見られる(側帯波、サイドバンド)。

### 4. 課題に対する設計方針

前項にて、遊星歯車機構を源として発生するギヤノイズの概要を述べた。

ギヤノイズの設計方針としては、まず遊星歯車機構のギヤノイズポテンシャルを決めるパラメータ設定を行う。歯諸元設定や、ピニオンギヤ数・歯数設定が挙げられる。これらのパラメータは、動力性能設計、レイアウト設計、工程設計、コスト設計といった、ノイズの性能設計とトレードオフの関係となる性能とのバランスを考えて設定する必要がある。

次に、遊星歯車機構の使用環境ともいうべき、支持構造の設計を行う。適切に支持構造の設計を行うことで、各々のギヤに生じるミスアライメントに起因するギヤかみ合い時の片当たりの防止や、振動伝達系のチューニングにつながる。

特にミスアライメントの設計指針に関しては経験的に諸説あるが大きく分けて二つある。一つ目は、各ギヤを支持しているベアリングをトランスミッションケースに圧入するなどして、できるだけミスアライメント量を小さくする場合である。二つ目は、反対に、意図的に支持部品間のかん合部

of pinions and the manner of using the carrier which is not stationary and is always rotating. It is caused by the fact that the pinion gears both rotate on their axis and revolve around the sun gear when the carrier turns because they are attached to the carrier.

	Vibration level	Direction of vibration	
		Rotational, axial	Transverse, tilting
Mesh phase difference	In phase	×	○
	Sequentially phased	○	×
	Counter phased	○	○
	Unequally spaced	△	△

Sideband order is observed as carrier rotates.

\*5pinions,  $\text{mod}(Zs/5)=2$  or 3  
 $Zs$  : number of teeth of sun gear

Fig. 2 Sideband

### 4. Design Guideline for Gear Noise

The gear noise stemming from planetary gear sets was briefly outlined in the preceding section. The first step on design guideline for gear noise is to design the parameters that determine the gear noise potential of a planetary gear set. Examples here include the determination of the tooth specification, the number of pinion gears and the number of gear teeth. These parameters must be determined by taking account of the performance balance that involves trade-offs between the noise performance design and the power performance design, layout design, process design, cost design and so on.

Next to be designed are the support structures, which might be called the usage environment of a planetary gear set. Designing suitable support structures prevents partial contact caused by individual gear misalignment that occurs when gears mesh and leads to tuning of the vibration transmission system.

Design guidelines for gear misalignment in particular can be broadly divided into two approaches, though there are many theories based on experience. One idea is to minimize the amount of misalignment as much as possible, for example, by press fitting the bearing supporting each gear to the transmission case. The other idea is, conversely, to give gears a self-centering action by intentionally providing play in the joints between structural parts. The latter guideline was adopted in this work.

にガタを設けるなどして、ギヤ自身の自動調芯作用(セルフセンタリング)を生かす場合である。今回は後者を選択した。

背景としては今回のような遊星歯車機構の場合は、インプットギヤ / アウトプットギヤの計二つのギヤで構成される平行軸ギヤ対と異なり、サンギヤ(CVT7で採用しているラビニオ式の場合二つ)・ピニオンギヤ(同ショートピニオン三つ・ロングピニオン三つ)・インターナルギヤと、関連するギヤの数が多く、さらに各々のギヤの支持に関わる部品まで含めると部品数が膨大のため、これらのミスアライメント量をゼロに近づけるには、大量生産する工業製品としては非現実的な精度が必要とされるためである。むしろ、理論的な理想状態としてはミスアライメントがゼロであるに越したことはない。

## 5. 設計事例の紹介

CVT7 W/Rの開発にあたり、これまで述べてきたラビニオ式遊星歯車機構のかみ合い部分を源として発生するギヤノイズに対し、性能面の改良内容として、前項で述べた設計方針に基づき、Fig.4のインターナルギヤと、これとかん合するハイクラッチのドラム間のスプラインかん合ガタの量を増やすことで、ノイズのレベル低減を図った。

インターナルギヤは主に後退時と、前進時のLowギヤ比→Highギヤ比切り替え時にノイズの源であるかみ合い伝達誤差を発生させるが、特に後者のシーンに関しては、副変速機の有段感を発生させないように、重視して設計した。

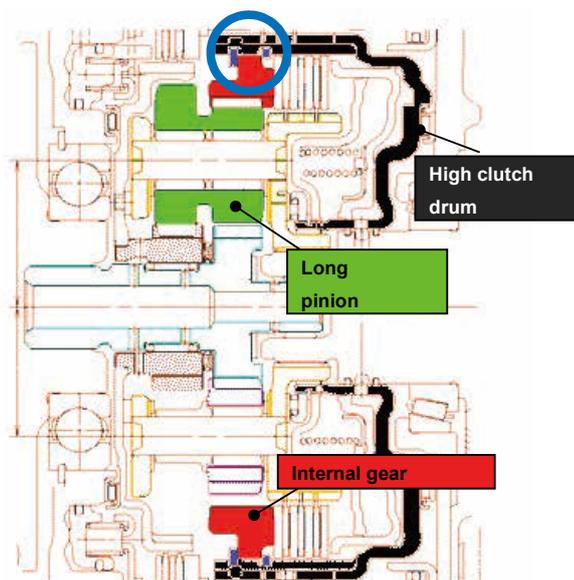


Fig. 4 Internal gear and high clutch drum (cross section)

That choice was made for the following reason. The planetary gear sets of the auxiliary gearbox involve many more gears, unlike a parallel-axis gear pair consisting of a total of two gears, i.e., one input gear and one output gear. The Ravigneaux planetary gear set adopted for the CVT7 has two sun gears, three short pinions, three long pinions and an internal gear. In addition, the part count becomes markedly larger when all the parts related to each gear support structure are included. Trying to reduce their misalignment to nearly zero would have required an unrealistic level of accuracy for mass-produced industrial parts. Obviously, there is theoretically no better ideal situation than to have no misalignment.

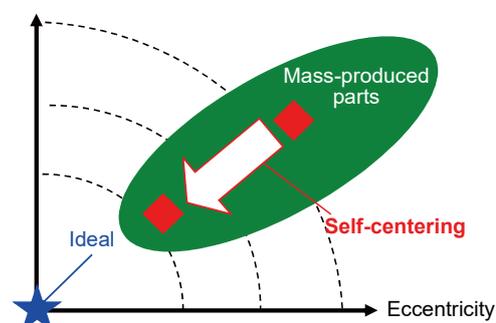


Fig. 3 Self-centering

## 5. Introduction of Design Examples

In the process of developing the CVT7 W/R, performance design improvements were made to reduce gear noise caused by meshing of the gears in the Ravigneaux planetary gear set as explained above. Based on the design guideline described in the previous section, the noise level was reduced by increasing the amount of play in the spline joints between the internal gear and the high clutch drum that meshes with it, as shown in Fig. 4. The internal gear produces transmission error that causes noise mainly in reverse and when switching from the Low gear ratio to the High gear ratio in forward travel. Emphasis was put on designing the auxiliary gearbox so as not to produce a stepped shift feel especially in the latter situation.

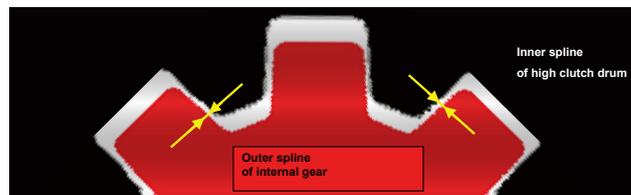


Fig. 5 Internal gear and high clutch drum (detail)

なお、インターナルギヤと、これとかん合するハイクラッチドラム間のスプラインかん合ガタの設定に関しては、ガタ量を大きくすることで不利方向になる他の性能があるため、それらトレードオフ性能と両立できるような設定値を決定する必要がある。Fig.6に示すように、セレクト時の駆動力変動、打音など、ガタを大きくすることで不利になる他の性能と両立できる諸元を設定した。

It will be noted that the amount of play in the spline joints between the internal gear and the high clutch drum that meshes with it had to be determined so as to be compatible with other performance attributes involving trade-offs. Setting the amount of play too large would be disadvantageous for such performance attributes. As illustrated in Fig. 6, a clearance specification was determined so as to be compatible with shift driving force fluctuation during garage shifting, rattle noise and other performance attributes that might be compromised by larger play.

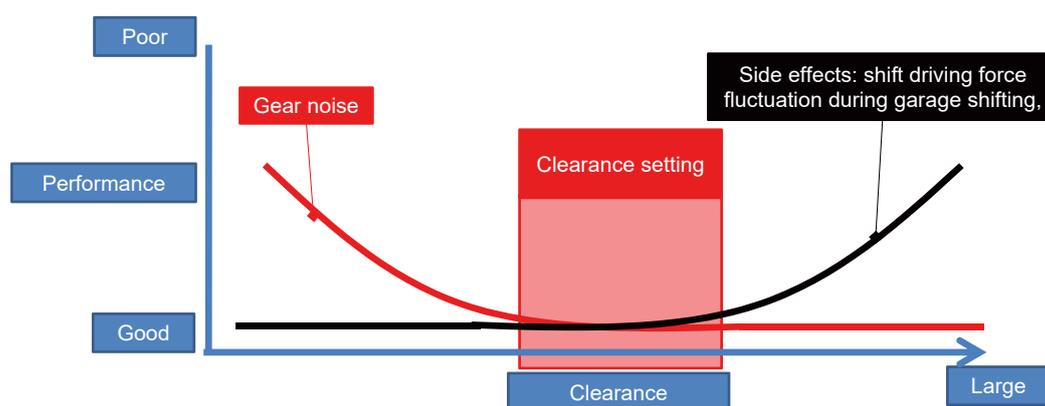


Fig. 6 Trade-off

## 6. おわりに

遊星歯車機構の支持方法の設計方針に関しては諸説あるが、今回Jatco CVT7 W/Rの開発に際した遊星ギヤノイズ性能の改良にあたり、副変速機に用いているラビニオ式遊星歯車機構のうち、インターナルギヤ支持部分のかん合ガタ量を適切に増加させることで自動調芯作用を積極的に取り入れ、ギヤノイズ低減の効果を得た。

最後に、当開発に際して多大なご協力をいただいた関係者の皆様に厚く御礼を申し上げます。

## 6. Conclusion

There are various ideas regarding design guidelines for methods of supporting planetary gear sets. In developing the new Jatco CVT7 W/R, an effort was made to reduce planetary gear noise. A self-centering action was positively applied to the internal gear of the Ravigneaux planetary gear set adopted for the auxiliary gearbox by suitably increasing the amount of play in the joint of the gear support structure. This measure had the effect of reducing gear noise.

Finally, the authors would like to profoundly thank everyone concerned for their invaluable cooperation with this development project.

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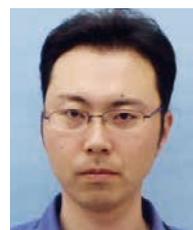
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# CVTプーリ用真空浸炭工法の開発とその進化

Development and Evolution of a Vacuum Carburizing Process for CVT Pulleys

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**抄 録** CVTプーリの熱処理は、ガス浸炭工法が広く普及し量産に利用されている。ガス浸炭工法は処理時間が長い、火災や爆発の危険性を持っている等のデメリットがある。ジャトコでは、ガス浸炭工法のデメリットを解消するため、真空浸炭工法の開発を行い、CVT用のプーリにおいては、他社に先駆け2004年より量産実用化できた。

その結果、プーリは、大幅な処理時間の短縮、品質の安定化、炎を使わない安全な作業などの多くのメリットを実現できた。本稿では量産化に際して発生した課題の対策と、真空浸炭工法の進化について報告する。

**Summary** A gas carburizing process is widely used in mass production operations as the heat treatment method for CVT pulleys. Gas carburizing requires a long treatment time and entails the risk of fire or explosion, among other disadvantages. At JATCO, we developed a vacuum carburizing process to eliminate these disadvantages of gas carburizing and implemented the process in our mass production system for CVT pulleys in 2004 ahead of other manufacturers.

As a result, numerous benefits were obtained, including a substantial reduction of the heat treatment time for pulleys, stabilization of quality and assurance of a safe working environment because flames are not used. This article explains the measures taken to address a stability issue that occurred when the process was implemented in mass production operations and the subsequent evolution of the vacuum carburizing process.

## 1. はじめに

CVTにおけるプーリは動力伝達の要であり、その強度を確保するために、浸炭熱処理工法が用いられている。特に、シーブ面およびボール、コロ溝部の硬化層は、一般部品より深くする必要があり、ガス浸炭工法では、長時間の処理が必要であった。

そのため、ジャトコでは処理時間を短縮し、生産性を上げ、かつ品質を安定化する方法として、真空浸炭工法を開発を行った。本稿では、真空浸炭工法の開発における課題とその対策、および量産の中で進化した機能について報告する。

## 1. Introduction

Pulleys are key parts for the transmission of power in a CVT. To ensure ample pulley strength, pulleys are subjected to a carburizing process for heat treatment. \*It is especially important to form a deeper hardened layer (i.e., case depth) on sheave faces and on the ball spline groove in contact with the roller bearing than on ordinary parts in general. Gas carburizing has traditionally required a long treatment time to accomplish that.

Therefore, JATCO developed a vacuum carburizing process as a technique for shortening the treatment time, boosting productivity and also stabilizing quality. This article describes the issues encountered in developing this vacuum carburizing process, the solutions implemented, and the evolution of the functionality of the process in mass production operations.

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## 2. 真空浸炭工法の課題

### 2.1. 真空浸炭工法のメリット

真空浸炭工法は、ガス浸炭工法と比較し以下の5つのメリットがある。

- ①浸炭処理時間が短い
- ②表面異常層がない
- ③ガスを変成する炉が不要である
- ④炎を使用せず安全性が高い
- ⑤CO<sub>2</sub>排出量が少ない(ガス浸炭比▲40%以上)

### 2.2. 真空浸炭工法のデメリット

真空浸炭工法は、炭化水素系の浸炭ガス(プロパン、アセチレン)を直接炉内に導入するため、以下の2つのデメリットがある。

- ①過剰浸炭が発生しやすい
- ②スス・タール等の副生成物が発生しやすい

ジヤトコでも、過剰浸炭により、局所的な黒色斑点が発生する課題があった。その発生状況をFig.1の写真で示す。

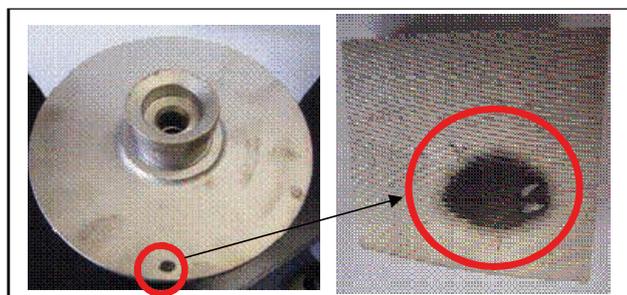


Fig. 1 Black spot by over carburizing

上記の課題を解決するため、浸炭ガスの噴射パターン、流量に着目して実験評価、解析を行った。

## 3. 実験方法

### 3.1. 供試材

実験は、JF010Eのプーリ(材質SCr420H)を用いた。

## 2. Issues in Vacuum Carburizing Process

### 2.1 Advantages of vacuum carburizing

Compared with gas carburizing, the vacuum carburizing process has the following five advantages.

- (1) Shorter carburizing time
- (2) No abnormal surface layer
- (3) No furnace is required for enriching the gas
- (4) High safety because no flame is used
- (5) Low level of CO<sub>2</sub> emissions (40% lower than gas carburizing)

### 2.2 Disadvantages of vacuum carburizing process

The vacuum carburizing process has the following two disadvantages because the hydrocarbon-based carburizing gas (propane or acetylene) is introduced directly into the furnace.

- (1) Overcarburizing tends to occur.
- (2) Soot, tar and other by-products tend to form.

The occurrence of local black spots due to overcarburizing also occurred at JATCO. Figure 1 shows the appearance of a typical black spot that occurred. For the purpose of resolving this issue, evaluation tests and analyses were conducted focusing on the injection pattern and flow rate of the carburizing gas.

## 3. Test Method

### 3.1 Tested material

Tests were conducted on JF010E pulleys made of JIS SCr420H high-carbon chromium bearing steel.

### 3.2 Test conditions

In order to clarify the basic characteristics of vacuum carburizing, the surface carbon content of carburized CVT pulleys was measured and the conditions giving rise to local overcarburizing were investigated for various carburizing gas injection patterns. A propane carburizing gas was used, which is characterized by a tendency to form soot, tar and other by-products. The carburizing process conditions were a carburizing temperature of 1223 K and a furnace pressure of 950 KPa. A continuous carburizing furnace was used in the tests.

### 3.2. 実験条件

真空浸炭の基礎特性を明らかにするため、浸炭ガスの噴射パターンを変化させ、CVTプーリの表面炭素濃度計測と局所的な過剰浸炭の発生状況を調査した。浸炭ガスはスス・タール等の副生成物が発生しやすい特性を持つプロパンガスを用い、浸炭条件は、浸炭温度1223k、炉内圧力950KPaとし、連続式真空浸炭装置を使用した。

## 4. 実験結果

### 4.1. 浸炭ガス噴射時間による表面炭素濃度推移

浸炭ガスの噴射タイミングを横軸に、CVTプーリの浸炭される炭素量を縦軸として実験した結果をFig.2に示す。

浸炭ガスの噴射回数に比例して表面炭素濃度は上昇するが、1223kにおける炭素固溶限1.4%を境に、表面炭素濃度の上昇は飽和している。

局所的な過剰浸炭は、浸炭温度の飽和炭素濃度1.4%を超えた際に発生した。

### 4.2. 浸炭ガス停止による炭素濃度推移

次に、一定量浸炭ガスを噴射し、CVTプーリに浸炭させたのち、浸炭ガスを停止した場合の炭素量を調査した。その結果をFig.3に示す。

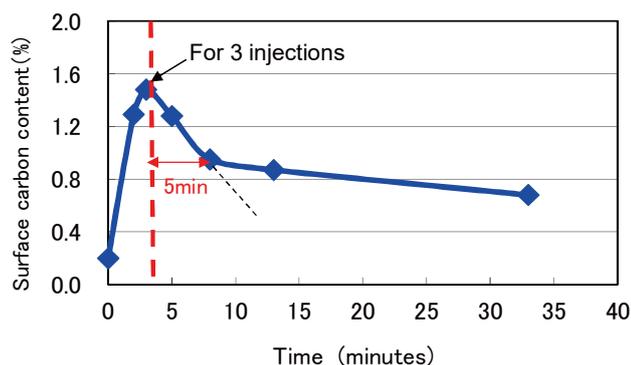


Fig. 3 Transition surface carbon content after gas shooting

一定量浸炭後にガスを停止させた場合、CVTプーリ内部へ炭素の拡散が進む。拡散のスピードは5分を超えると著しく低下する。

## 4. Test Results

### 4.1 Change in surface carbon content relative to carburizing gas injection time

Typical test results are presented in Fig. 2. The measured surface carbon content of the CVT pulleys is shown on the vertical axis as a function of the number of carburizing gas injections on the horizontal axis.

The surface carbon content increased in proportion to the number of times the carburizing gas was injected. At 1223 K, the increase in the surface carbon content saturated at the solid solubility limit of carbon of 1.4%.

Local overcarburization occurred when the carbon surface content exceeded the saturated carbon content of 1.4% at a carburizing temperature of 1223 K.

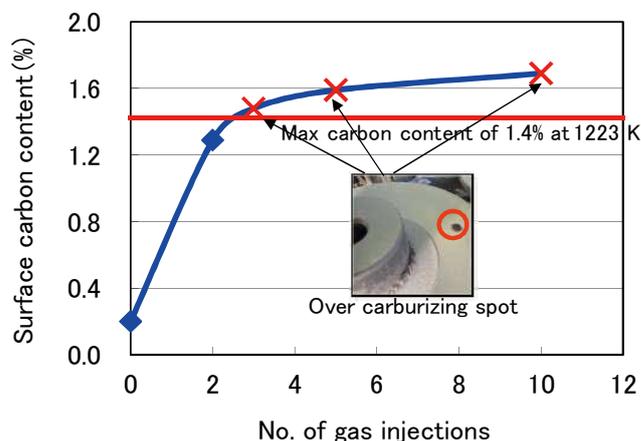


Fig. 2 Structure of baffle plate

### 4.2 Change in carbon surface content due to suspension of carburizing gas injection

The surface carbon content was then investigated when the injection of the carburizing gas was suspended after injecting a specified quantity of gas to carburize the pulley surface. The results obtained are presented in Fig. 3.

When the injection of the carburizing gas was suspended after performing a specified amount of carburization, carbon continued to diffuse into the interior of the CVT pulleys. After 5 min. elapsed, the rate of diffusion dropped sharply.

### 4.3. 浸炭ガス噴射パターンの最適化

上記の実験結果から、過剰浸炭を防止し浸炭と拡散を効率よく実施する条件の概念図を、Fig.4に示す。

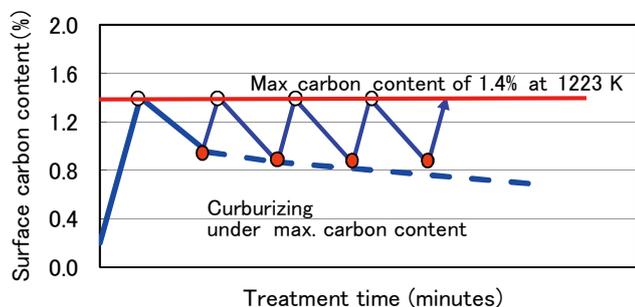


Fig. 4 Logical pattern of gas shooting

局所的な過剰浸炭を防止し、効率的な浸炭を行うためには、CVTプーリの表面炭素濃度を飽和炭素濃度以下に維持することが重要であり、浸炭ガスの噴射パターンと浸炭・拡散の関係を把握することでコントロールができることがわかった。

### 4.4. 浸炭ガス量にしめる固溶炭素量の割合

浸炭ガス量と浸炭量の関係を明らかにするため、浸炭ガス量にしめる固溶炭素量の割合を調査した。固溶炭素量の割合は、供給した浸炭ガス中に含まれる炭素量に対して、CVTプーリに固溶(浸炭)した炭素量である。以降これを固溶炭素率とする。

固溶炭素率を算出するためのパラメータとして、浸炭ガス量、CVTプーリの総面積、浸炭後の重量差との関係を調査した。

浸炭ガス量とCVTプーリへの固溶炭素率の関係をFig.5に示す。

投入した浸炭ガス中の炭素量のうち、CVTプーリへの固溶炭素率が4.6~12.1%の場合に、局所的な過剰浸炭が発生する。同様に、固溶炭素率が25.4%以上の場合に、浸炭不足が発生する。

これは、固溶炭素率が低い場合は、投入した浸炭ガス量が過剰であり、固溶炭素率が高い場合は、浸炭ガス量が不足していることを意味する。

以上の結果をふまえ、当社ではCVTプーリの表面積と固溶炭素率の関係をFig.6におさめることとした。最適な固溶炭素率と部品の表面積より、最適ガス量を選定できる。

### 4.3 Optimization of carburizing gas injection pattern

Based on the foregoing test results, injection conditions were investigated for promoting efficient carburization and diffusion while preventing overcarburization. The concept of the injection pattern is diagrammed in Fig. 4.

To obtain efficient carburization while preventing local overcarburization, it is important to keep the surface carbon content of CVT pulleys below the saturated carbon level. It was found that the surface carbon content could be controlled by making clear the relationship between the carburizing gas injection pattern and resultant carburization and diffusion.

### 4.4 Proportion of solute carbon content in carburizing gas flow

The proportion of the solute carbon content in the quantity of carburizing gas supplied was investigated to make clear the relationship between the gas flow rate and the amount of carburization obtained. The proportion of the solute carbon content is the amount of carbon dissolved (diffused) into the CVT pulleys in relation to the quantity of carbon in the carburizing gas supply. This is referred to here as the solute carbon ratio.

The relationship between the quantity of carburizing gas, total CVT pulley area and the weight difference following carburization was investigated as a parameter for use in calculating the solute carbon ratio.

Figure 5 shows the relationship between the carburizing gas flow rate and the solute carbon ratio introduced into the CVT pulleys. Among the various quantities of carburizing gas injected, it is seen that local overcarburizing occurred when the solute carbon ratio introduced into the CVT pulleys was in a range of 4.6-12.1%. Similarly, when the solute carbon ratio was above 25.4%, carburization was insufficient.

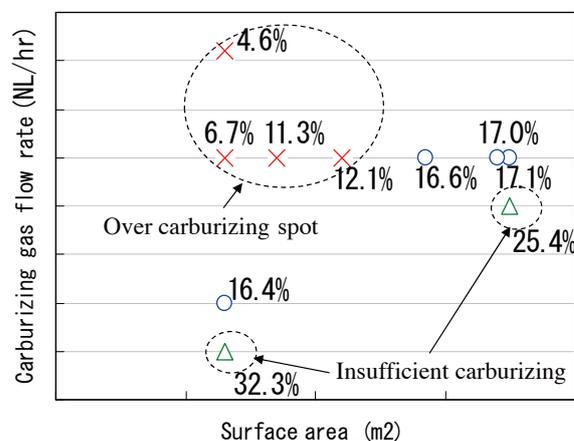


Fig. 5 Relation of gas flow and surface area of pulleys to reacted carbon content

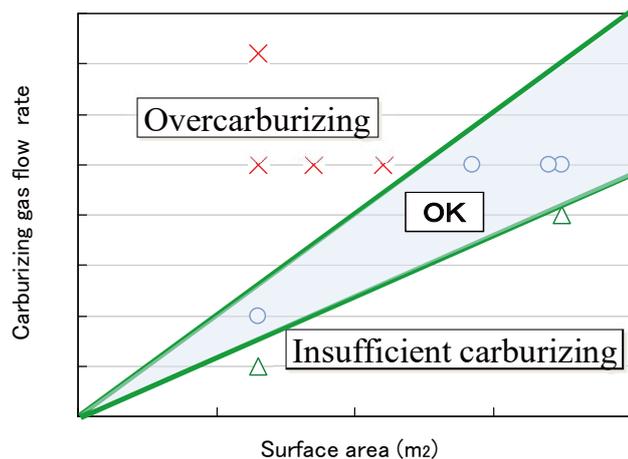


Fig. 6 Proper range of reacted carbon content

また、固溶炭素率は、以下の実験式(1)で表せる。

$$D = \left( 22.4 \times \frac{A \times F}{T \times n \times C \times V} \right) \quad (1)$$

ここに、

固溶炭素率：D (%)

被処理物の総表面積：A (cm<sup>2</sup>)

フラックス値：F (g/cm<sup>2</sup>)

浸炭ガス噴射時間：T (hr)

浸炭ガス：C<sub>n</sub>H<sub>m</sub>

炭素原子重量：C (=12.01g)

標準状態での時間当たりガス流量：V (NL/hr)

※22.4は、モル体積を表す (L/mol)

である。

## 5. 量産への適用と検証

これまでの実験結果から処理条件を設定し、量産を実施した。量産の条件が、適正であることを検証するため、浸炭ガス噴射時間と浸炭量の関係を調査した。その結果をFig.7に示す。なお、浸炭量は、丸棒型のテストピースを用い浸炭前後の重量から浸炭量を測定した。

浸炭ガス噴射時間に対し、浸炭量は比例して増加している。量産条件は、過剰な浸炭や、浸炭の不足が発生していないことがわかる。

The results indicate that the injected carburizing gas flow rate was excessive when the solute carbon ratio was low and that the carburizing gas flow rate was insufficient when the solute carbon ratio was high.

Based on the foregoing results, at JATCO we have defined the relationship between the CVT pulley surface area and the solute carbon ratio such that it falls in the range shown in Fig. 6. This makes it possible to select the optimum gas flow rate based on the optimal solute carbon ratio and part surface area.

The solute carbon ratio is expressed by the following experimental equation (1).

$$D = \left( 22.4 \times \frac{A \times F}{T \times n \times C \times V} \right) \quad (1)$$

where,

D: solute carbon ratio (%)

A: total surface area of pulley being carburized (cm<sup>2</sup>)

F: flux value (g/cm<sup>2</sup>)

T: carburizing gas injection time (hr)

C<sub>n</sub>H<sub>m</sub>: carburizing gas

C: carbon atomic mass (= 12.01 g)

V: gas flow rate per unit of time under standard process conditions (NL/hr)

22.4: molar volume (L/mol)

## 5. Application to Mass Production and Verification

The carburizing conditions were defined on the basis of the foregoing experimental results and applied to the mass production process of CVT pulleys. The relationship between the carburizing gas injection time and amount of carburization obtained was investigated to verify whether these mass production conditions were optimal or not. The results are presented in Fig. 7. The amount of carburization obtained was determined by measuring the weight of round test pieces before and after carburization.

The results show that the amount of carburization increased in proportion to the gas carburizing injection time. It was confirmed that neither overcarburization nor insufficient carburization occurred with these mass production conditions.

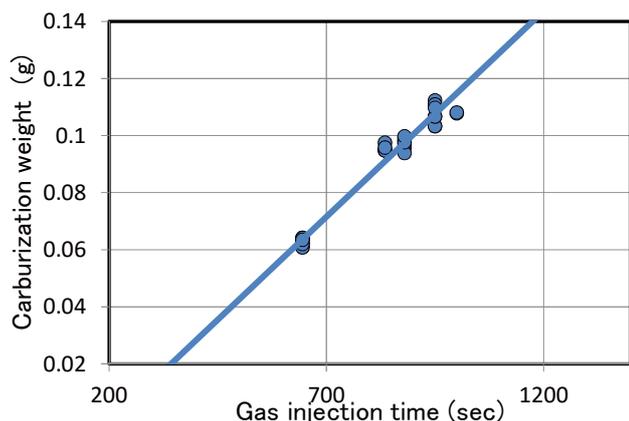


Fig. 7 Relation between gas shooting time and carburizing weight

## 6. 真空浸炭工法の課題対策

CVTプーリの真空浸炭工法の課題として、カーボン濃度安定化(過剰浸炭の防止)を実施した。カーボン濃度安定化のためには、以下の2点が必要となる。

- ① 浸炭ガスの噴射時間、停止時間を制御し、CVTプーリの表面炭素濃度の最大値を、固溶限以下に維持する。
- ② 浸炭ガスの流量を制御し、浸炭に利用される炭素の割合(固溶炭素率)を一定に維持する。

以上の制御をすることで、浸炭量の適正化だけでなく、浸炭処理時間の大幅な短縮、スス・タール等の副生成物の削減もできた。

## 7. 真空浸炭工法のさらなる進化

ジャトコでは、本技術を利用し、海外における浸炭熱処理は真空浸炭工法を全面的に採用中である。

さらなる進化として、2010年以降の真空浸炭炉の浸炭ガスは、従来のプロパンより、反応性が高く副生成物の発生が少ないアセチレンを採用している。この結果、サイクルタイムで7%の短縮、副生成物の発生を50%以上の削減を達成した。

設備の構成も、1モジュールで従来比+33%の能力を持つ構造とし、投資の削減も行った。

ジャトコは、CVTプーリにおける真空浸炭工法のリーディングカンパニーである。今後もこれまでの成果を活かし、新たな改善を行うことで、真空浸炭工法のさらなる進化を続けてゆきたい。

## 6. Solution to Overcarburization Issue in Vacuum Carburizing Process

One issue in the vacuum carburizing process for CVT pulleys was to stabilize the carbon concentration so as to prevent overcarburization. The following two points were necessary for the stabilization of the carbon content.

- (1) The maximum surface carbon content of the pulley surface must be kept below the solid solubility limit by controlling the carburizing gas injection and suspension times.
- (2) The proportion of carbon used in carburization process (i.e., solute carbon ratio) must be kept constant by controlling the carburizing gas flow rate.

Controlling these process parameters not only optimized the amount of carburization obtained, it also greatly shortened the carburization process time and reduced the quantity of tar, soot and other by-products.

## 7. Further Evolution of Vacuum Carburizing Process

JATCO is now fully adopting this vacuum carburizing technology in the carburizing process at the company's overseas plants.

One example of the further evolution of this process since 2010 is the adoption of acetylene as the carburizing gas introduced into the vacuum carburizing furnace. Acetylene has higher reactivity and produces fewer by-products than the propane gas used previously. As a result, the cycle time has been shortened by 7% and the formation of by-products has been reduced by more than 50%.

Capital investment in equipment has also been reduced by changing the equipment configuration to a structure that increases the process capacity per module by 33% over the previous level.

JATCO intends to remain the leading company in the vacuum carburization process for CVT pulleys in the coming years. We want to continue to evolve the vacuum carburizing process further by implementing new improvements based on the results obtained to date.

## 8. 謝辞

最後に、本活動を進めるにあたり、ご協力いただいた設備メーカーの皆様ならびに関係各位に感謝する。

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## 8. Acknowledgments

Finally, the authors would like to express their appreciation to all the equipment manufacturers and to everyone concerned for their invaluable cooperation with the development of this vacuum carburizing process.

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# 中型FWD車用Jatco CVT8 HYBRIDの開発

Introducing the Jatco CVT8 HYBRID for Midsize FWD Cars

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**抄 録** ジャトコは、2015年5月からエクストレイル HYBRIDに搭載されたJatco CVT8 HYBRID(以下「JF019E」(当社型式名)とする)の生産を2015年3月から開始した。JF019Eは、2013年7月に発売を開始した、Pathfinder、QX60搭載用Jatco CVT8 HYBRID(以下「JF018E」(当社型式名)とする)をベースとしたトランスミッションである。本稿では、このJF019Eの商品概要を紹介する。

**Summary** In March 2015, JATCO launched production of the Jatco CVT8 Hybrid (JF019E model) that has been mounted on the X-Trail Hybrid since May of last year. The JF019E transmission is based on the Jatco CVT8 Hybrid (JF018E model) that was released in July 2013 and is mounted on the Pathfinder and Infiniti QX60. This article presents a product overview of the JF019E.

## 1. はじめに

## 1. Introduction

今回ジャトコは、新たに日産自動車株式会社(以下「日産」とする)と共同で、国内向けにCVT8シリーズの中型FWD車用HEVトランスミッションを開発した。2013年7月に発売を開始した大型FWD車用HEVトランスミッションであるJF018Eは海外向け車両へ搭載されるトランスミッションであったため、日本国内でのHYBRID発売を望むお客さまの声に応えるべく開発したトランスミッションであり、下記をコンセプトに開発した。

1. 燃費のさらなる向上
2. 変速品質のさらなる向上
3. 徹底した部品の共用化

以下本文にて詳細を説明する。

## 2. システム概要

HEVシステムは、JF018Eと同じ1-motor 2-clutch(以下「1M2CL」とする)方式を採用、その構成は、1つのElectric Motor兼Generator(以下「MG」とする)と2つのClutchからなる。

JATCO and Nissan Motor Co., Ltd. jointly developed a new CVT8 series hybrid transmission for application to midsize front-wheel-drive (FWD) cars sold in the Japanese market. In July 2013, JATCO released the JF018E hybrid transmission for application to large FWD vehicles in overseas markets. The new CVT8 Hybrid described here was developed in response to requests from customers who wanted JATCO to provide a hybrid transmission in the Japanese market. This transmission was developed around the following concepts:

1. to further improve fuel economy, and
2. to further enhance shift quality, and
3. to promote thorough sharing of parts.

The details of the JF019E are described in the following sections.

## 2. System Overview

The JF019E adopts a 1-motor 2-clutch (1M2CL) hybrid system like that of the JF018E. The system comprises one electric motor-generator (MG) and two clutches. A conceptual diagram of the 1M2CL system is shown in Fig. 1.

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- (1) エンジンの動力をMGに伝えるClutch (CL1)
- (2) トルクコンバータに変わる発進デバイスのClutch (CL2)
- (3) CL1とCL2の間に設置されているMG

これらをコントロールすることでさまざまな走行シーンに合った作動モードを形成でき、燃費と動力性能を自在に制御することを可能としている。Fig.1に1M2CLの概念図を示す。

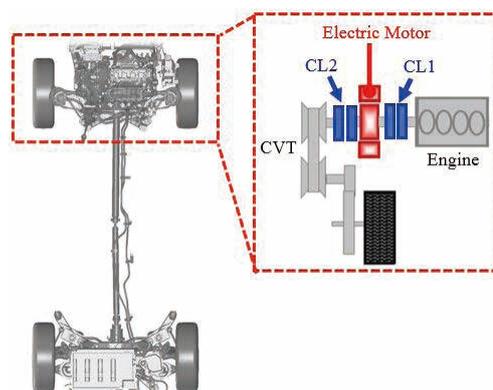


Fig. 1 Conceptual structure of 1M2CL system

## 2.1. 燃費のさらなる向上

JF019Eを開発するにあたり、さらなる燃費向上の目標を達成するため、EVでの走行頻度の拡大を図っている。Table 1にJF018EとJF019Eの仕様差を示す。

EVでの走行頻度の拡大に伴い、JF018Eと比較してモーター走行の頻度が増加するため、トランスミッションとしてモーターアイドルの低回転化に取り組んだ。

- (1) Clutch-1 (CL1) transmits engine power to the MG unit.
- (2) Clutch-2 (CL2) functions as the start-off device in place of a torque converter.
- (3) The MG unit is positioned between CL1 and CL2.

Table 1 Powertrain specifications

		Hybrid system for large FWD cars	Hybrid system for midsize FWD cars
Car		Infiniti QX60 Hybrid	Nissan X-TRAIL Hybrid
Hybrid System		Parallel Hybrid System 1-motor 2-clutch	←
Engine	Disp.	2.5 L	2.0 L
	Type	I4 Supercharger	I4
Transmission		Transverse (FWD)	←
CL1	Type	Dry multi-plate clutch 4 plates	Dry multi-plate clutch 3 plates
CL2	Type	Wet multi-plate clutch Fwd: 4 plates Rev: 5 plates	Wet multi-plate clutch Fwd: 4 plates Rev: 4 plates
Motor	Max power	15 kW	30 kW

本 HEV システムはエンジンを停止するEV状態において、停車中でもMGを回転させることによってオイルポンプを作動させ、油圧システムを稼働させている。(モーターアイドル)

この時、MGの回転速度が速ければそれだけ消費電力も大きくなる。

CVT作動油(以下CVTF)は温度が低いほど粘度が高くなる性質を持っているため、リークが減ることを加味すると必要なMG回転速度は温度が低いほど遅くて良い。

These constituent parts are controlled to create operating modes matching various driving situations, thereby allowing flexible control of fuel economy and power performance.

### 2.1 Further improvement of fuel economy

In the course of developing the JF019E, efforts were made to increase the frequency of EV mode driving in order to attain the target for further improving fuel economy. Table 1 compares the specification differences between the JF018E and JF019E.

Owing to the expanded frequency of EV mode driving, the motor is used to propel the vehicle more often compared with the JF018E. Therefore, the JF019E was built to enable the motor to operate at a lower speed during idling. In the

そこで、CVTF油温に応じて必要最低限の回転速度でMGを作動させることにより、消費電力を抑え、燃費を向上する制御とした。Fig.2に概念図を示す。

JC08モードにおいて車両が停車している時間は全体の29%を占める(Fig.3に概念図を示す)が、その間MG回転速度を最大50%下げることによって燃費の向上を図ることができた。

実用においても車両停止の多い使い方では効果が期待できる制御である。

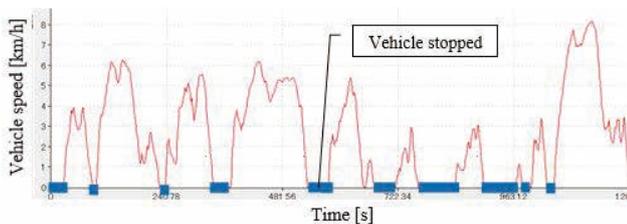


Fig. 3 Intervals when vehicle is stopped in JC08 test mode

## 2.2. 変速品質のさらなる向上

本HEVシステムは1M2CL方式を採用しており、CL2はWet Start Cluch(以下WSCとする)機能として使われる。WSC課題の一つとして、発進直後の低速度域のトルクコントロール性があり、要求性能を達成させるために、CL2のトルク容量のバラツキを低減させる学習制御を採用している。

JF019Eを開発するに当たり、上記学習制御のさらなる改良を行った。

従来の学習制御はWSC中にCL2油圧を段階的に下げていき、CL2トルクがゼロとなるポイントを探る学習制御であったが、WSC中のCL2トルクを、MG電流を監視することによってトルクセンサー代わりとしてCL2トルクを推定し、CL2指令に対する誤差を補正する学習制御を新たに開発した。Fig.4に学習プロセスを示す。

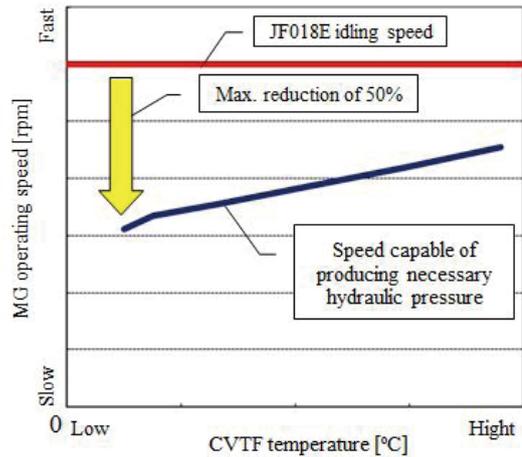


Fig. 2 New MG speed control

EV mode of this hybrid system with the engine stopped, the MG unit is operated to drive the oil pump and the hydraulic system even while the vehicle is at rest. This operating state is referred to as motor idling.

The faster the MG unit operates during motor idling, the more electric power it consumes. One characteristic of the CVT fluid (CVTF) is that its viscosity increases with decreasing temperature. Accordingly, taking into account the reduction of fluid leakage, the necessary MG operating speed should be set lower as the fluid temperature decreases.

With the JF019E, the MG unit is operated at the minimum necessary speed according to the CVTF temperature. This speed control holds down the consumption of electric power to improve vehicle fuel economy. The concept of this new MG speed control is shown in Fig. 2.

Under Japan's JC08 test mode, the time the vehicle is stopped accounts for 29% of the total test cycle, as shown in the conceptual diagram in Fig. 3. Fuel economy was improved by lowering the MG operating speed by a maximum of 50% during those intervals. In real-world operation, this speed control is expected to be effective in driving situations where the vehicle is frequently at rest.

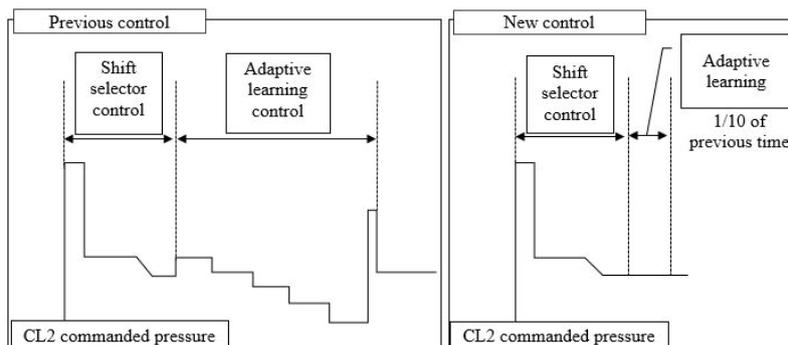


Fig. 4 Adaptive learning control process

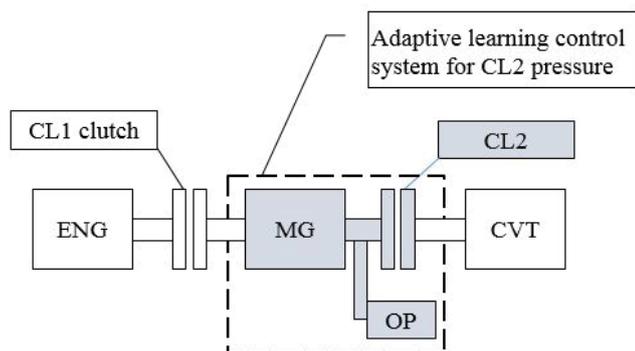


Fig. 5 Adaptive learning control system for CL2 pressure

MGをトルクセンサー代わりとしてCL2トルクを推定するメカニズムを以下に示す。Fig.5にシステム概略図を示す。

WSC中(CL2半締結時)のMG軸まわりのトルク釣り合い式は(1)式となる。

$$T_{mg@wsc} = T_{fric\_mg} + T_{fric\_op} + T_{cl2} \quad (1)$$

$T_{mg@wsc}$ : MG出力トルク@WSC中

$T_{fric\_mg}$ : MGのフリクショントルク

$T_{fric\_op}$ : OPのフリクショントルク

$T_{cl2}$ : CL2トルク

CL2解放時のMG軸まわりのトルク釣り合い式は(2)となる。

$$T_{mg@n} = T_{fric\_mg} + T_{fric\_op} \quad (2)$$

$T_{mg@n}$ : MG出力トルク@CL2解放時

上記(1), (2)式より, WSC中のCL2トルクは(3)式のように推定できる。

$$T_{cl2} = T_{mg@wsc} - T_{mg@n} \quad (3)$$

ここでWSC中の指令CL2トルク( $TT_{cl2}$ )と(3)で求められるCL2トルクとの差がバラツキによる誤差( $\Delta T_{cl2}$ )となるため, 誤差と補正量( $\Delta P_{cl2}$ )はそれぞれ(4), (5)式となる。

$$\Delta T_{cl2} = TT_{cl2} - T_{cl2} \quad (4)$$

$$\Delta P_{cl2} = \Delta T_{cl2} / \mu \cdot N \cdot D \cdot A \quad (5)$$

$\mu$ : クラッチ摩擦係数

$N$ : クラッチ枚数

$D$ : クラッチ有効系

$A$ : クラッチピストン受圧面積

## 2.2 Further improvement of shift quality

The CL2 clutch in this 1M2CL hybrid system functions as a wet start-off clutch (WSC). One issue of a WSC is torque controllability in the low speed range right after vehicle launch. Adaptive learning control was adopted for CL2 to reduce variation in its torque capacity in order to attain the required performance. This adaptive learning control was further improved in the process of developing the JF019E.

The previous adaptive learning control reduced the CL2 pressure in stages during partial clutch engagement (WSC operation) in searching for the point where CL2 torque became zero. For the JF019E, a new adaptive learning control was developed that estimates CL2 torque during WSC operation by monitoring the MG current instead of using a torque sensor and corrects any error in the CL2 torque command. The adaptive learning control process is outlined in Fig. 4.

The mechanism by which the CL2 torque is estimated based on the MG current in place of using a torque sensor is explained below. A schematic of the adaptive learning control system for the CL2 pressure is shown in Fig. 5

The torque balance around the MG shaft during WSC operation while CL2 is partially engaged is given by Eq. (1).

$$T_{mg@wsc} = T_{fric\_mg} + T_{fric\_op} + T_{cl2} \quad (1)$$

$T_{mg@wsc}$ : MG output torque during WSC operation

$T_{fric\_mg}$ : MG friction torque

$T_{fric\_op}$ : oil pump friction torque

$T_{cl2}$ : CL2 torque

The torque balance around the MG shaft when CL2 is disengaged is given by Eq. (2).

$$T_{mg@n} = T_{fric\_mg} + T_{fric\_op} \quad (2)$$

$T_{mg@n}$ : MG output torque when CL2 is disengaged

Based on Eqs. (1) and (2) above, CL2 torque during WSC operation can be estimated as shown in Eq. (3).

$$T_{cl2} = T_{mg@wsc} - T_{mg@n} \quad (3)$$

The difference here between the commanded CL2 torque ( $TT_{cl2}$ ) during WSC operation and the CL2 torque calculated with Eq. (3) becomes error ( $\Delta T_{cl2}$ ) due to torque variation. Accordingly, this error and the amount of compensation ( $\Delta P_{cl2}$ ) are given by Eqs. (4) and (5), respectively.

$$\Delta T_{cl2} = TT_{cl2} - T_{cl2} \quad (4)$$

$$\Delta P_{cl2} = \Delta T_{cl2} / \mu \cdot N \cdot D \cdot A \quad (5)$$

$\mu$ : clutch friction coefficient

$N$ : number of clutch plates

$D$ : effective clutch diameter

$A$ : pressure receiving area of clutch piston

本学習制御により、従来はクラッチのすべり回転が起ることを捕えて学習完了していたものがクラッチすべり条件を予測できるようになったために、学習完了までの時間が大幅に短縮できた。具体的には、CL2トルク初期ズレをアジャストする時間が従来比で約1/10と短縮でき、より初期段階から安定したWSC性能を達成させることができた。Fig.6に学習前後の波形を示す。

### 2.3. 徹底した部品の共用化

JF019EはCVT8, JF018Eとの部品共用化率を88.5%とすることで構成部品における新規部品数の増加を抑制した。

またJF018Eの生産開始時の設備改造(モーター組み付け工程, ファイナルテスター, ユニット外観洗浄機)においてJF019Eの機種追加も考慮して設備改造を実施していたため、コストアップの抑制を実現できた。Fig.7にCVT8, JF018EとJF019Eの断面図を示す。

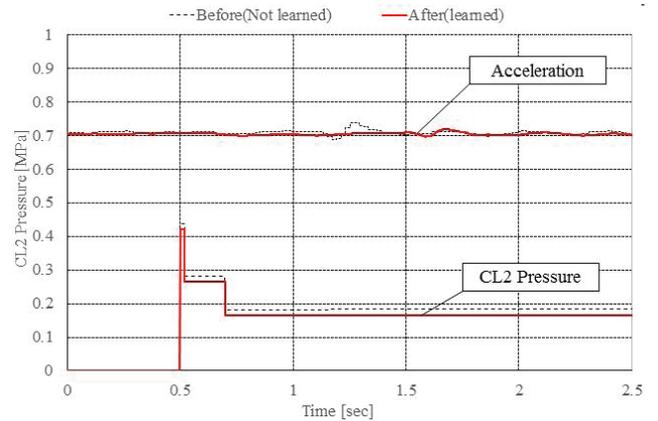


Fig. 6 The effect of MP Learning

The previous system terminated adaptive learning control when it detected the slipping of the rotating clutch. The new adaptive learning system is capable of predicting the conditions under which clutch slipping occurs, thereby greatly shortening the time to the completion of adaptive learning. Specifically, the interval in which the initial CL2 torque variation is adjusted is shortened to approximately one-tenth of that of the previous system. This now makes it possible to obtain stable WSC performance from an earlier stage. A schematic diagram of the adaptive learning control system is shown in Fig. 6.

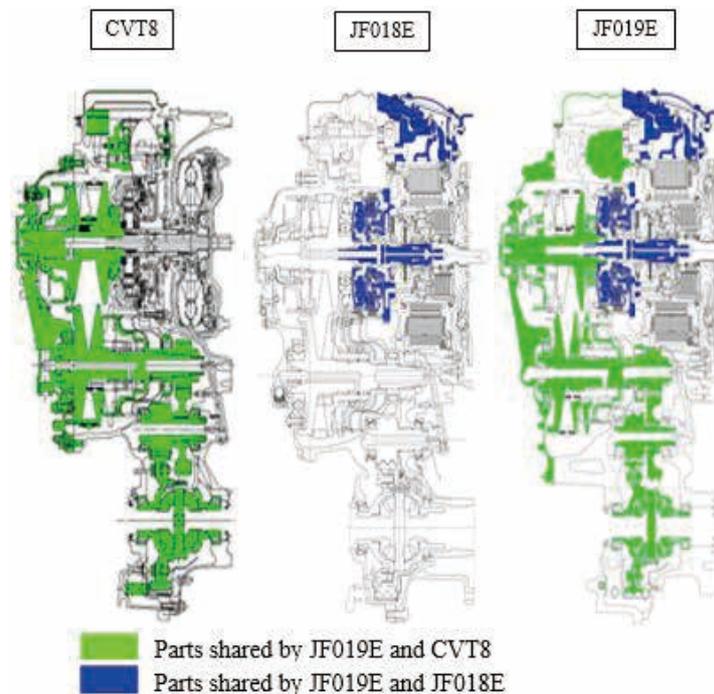


Fig. 7 Cross-sectional views of CVT8, JF018E and JF019E

### 3. まとめ

JF018Eに対してJF019Eはモーターアイドル回転速度を最大50%下げることにより高い燃費目標を達成している。

また変速品質においても、CL2学習制御のロジックを変更することで、早期でのCL2学習が可能となり、使用初期の変速フィーリングを大幅に向上できた。

今回JF019Eの開発にあたり、ご協力いただいた社内外的関係諸氏に感謝の意を表す。

### 4. 参考文献

小長谷 文人, 大曾根 竜也, 寺内 政治, Jatco CVT8 HYBRID商品紹介, Jatco Technical Review No.13, pp.17-24, (2014)

### 2.3 Thorough sharing of parts

The JF019E shares 88.5% of its parts with the base CVT8 and the JF018E. This high rate of commonality held down the number of new parts among the system components.

Moreover, the addition of the JF019E model to the product mix was taken into account at the time the production facilities were reorganized for launching production of the JF018E. That reorganization included the motor installation process, final tester and transmission exterior washer, which also held down cost increases for the JF019E.

Figure 7 presents cross-sectional views of the CVT8, JF018E and JF019E.

### 3. Conclusion

The JF019E attains the high fuel economy target set for this unit by reducing the motor speed during motor idling by as much as 50% compared with the JF018E. With regard to shift quality, the CL2 adaptive learning control logic was improved to enable adaptive learning of CL2 pressure more quickly. This has made it possible to enhance the shift feel significantly at the outset of driving.

The authors would like to thank everyone inside and outside the company for their invaluable cooperation with the development of the new JF019E.

### 4. References

Fumito Konagaya, Tatsuya Osone, Seiji Terauchi, Introducing the Jatco CVT8 HYBRID, Jatco Technical Review No.13, pp.17-24, (2014)

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# 韓国GM社向けChevrolet Spark用 Jatco CVT7 (JF015E)の紹介

Introducing the Jatco CVT7 (JF015E) for GM Korea's Chevrolet Spark

2015年8月に韓国で発売された韓国GM社の新型車「Spark」(1.0L / 1.4L)にJatco CVT7(JF015E)が搭載されました。Sparkは「優れた燃費性能, 加速性能」を主な特長としており, クラストップの燃費性能を実現しています。

最新制御技術を採用したCVT7は新型3気筒および4気筒エンジンとの組合せにより, 加速性能の向上だけでなくアイドルストップによる燃費向上, ステップ変速制御(D-STEP)による運転性の向上を実現し, お客様から好評を得ています。

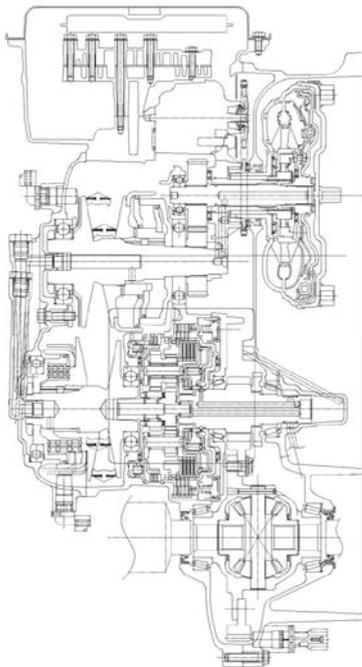


Fig. 1 Main cross-sectional view

The Jatco CVT7 (JF015E) is mounted on the new-generation Spark that was released by GM Korea Company in the Korean market in August 2015 and is available with 1.0L and 1.4L engines. The principal features of the Spark are its outstanding fuel economy and acceleration performance. The car achieves class-leading fuel economy.

Incorporating the latest control technologies, the CVT7 is mated to the new 3-cylinder and 4-cylinder engine. In addition to improving acceleration performance, the CVT7 features automatic stop/start capability for improving fuel economy and Dynamic Step Shift (D-STEP) control for enhancing driveability. Its performance is highly popular among customers.

Table 1 Specifications of JF015E

Torque capacity	95 Nm / 128 Nm	
Torque converter size	185 / 205 mm	
Pulley ratios	2.200~0.550	
Auxiliary transmission gear ratios	1st	1.821
	2nd	1.000
	Rev	1.714
Ratio coverage	7.3	
Final gear ratio	3.882	
Number of selector positions	5 (P, R, N, D, L)	
Overall length	339 mm	
Weight (wet)	70 kg	

■ Typical model fitted with the JF015E CVT ■



Spark

# マツダ向け ボンゴ用 5速AT JR507Eの紹介

Introducing the JR507E 5-speed AT for the Mazda Bongo

マツダ株式会社の「ボンゴ(トラック/バン)」には従来当社のFR車用4速AT(JR405E)が搭載されていましたが、新型ボンゴ(2016年2月初旬発表)にはFR車用5速AT(JR507E)が搭載されました。

4速ATに対し、レシオカバレッジ拡大やロックアップ領域の拡大により優れた動力性能や燃費性能を実現しました。また、変速線の改良により最適なシフトフィーリングが実現され、また多段化によってシフトダウン時の回転変化が小さくなったことで音振性能が向上し、お客さまから大変好評を得ています。

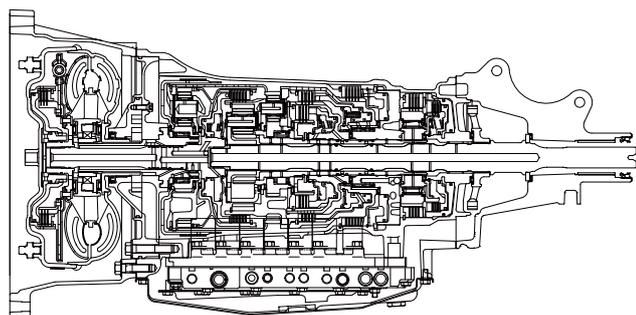


Fig. 1 Main cross-sectional view

The Mazda Bongo was previously equipped with JATCO's JR405E 4-speed AT for rear-wheel-drive (RWD) vehicles. The new-generation Bongo, released in early February 2016, is fitted with JATCO's JR507E 5-speed AT for RWD vehicles.

Compared with the previous 4-speed AT, ratio coverage and the lockup region of the 5-speed AT have been expanded to deliver outstanding power performance and fuel economy. In addition, improved shift lines achieve the optimal shift feel. The additional gear ratio reduces the change in engine speed when downshifting, thereby improving noise and vibration performance. These performance attributes are very popular among customers.

Table 1 Specifications of JR507E

Torque capacity	150 Nm	
Torque converter size	250 mm	
Gear ratios	1st	3.841
	2nd	2.352
	3rd	1.529
	4th	1.000
	5th	0.839
	rev	2.764
Ratio coverage	4.578	
Final gear ratio	3.909	
Number of selector positions	6 (P, R, N, D, S, L) + Hold mode	
Overall length	2WD	769.7 mm
	4WD(without transfer)	661.9 mm
Weight (wet)	2WD / 4WD	83 kg

## ■ Typical models fitted with the JR507E AT ■



Bongo Truck



Bongo Van

マツダ株式会社の利用合意を受けているので、他への転載、転用を一切禁ずる。

# 日産自動車向けMaxima用Jatco CVT8 (JF017E)の紹介

Introducing the Jatco CVT8 (JF017E) for the Nissan Maxima

2015年5月に日産自動車株式会社より北米で発売された新型「Maxima」に当社のJatco CVT8 High Torque (JF017E)が搭載されました。

JF017Eではその特徴である低フリクションやワイドレシオカバレッジにより、高い燃費性能と動力性能を両立させています。

また、VQ35 H/O (ハイアウトプット) エンジンとの組み合わせにより、さらに爽快な加速フィーリングを実現し、お客さまから好評を得ています。

The Jatco CVT8 High Torque (JF017E) model is mounted on the new-generation Nissan Maxima that Nissan Motor Co., Ltd. released in North America in May 2015. Featuring low friction and wide ratio coverage, the JF017E provides high fuel economy combined with excellent power performance. In addition, this CVT is mated to the VQ35 H/O (High Output) engine to deliver a more exhilarating feeling of acceleration, which is highly popular among customers.

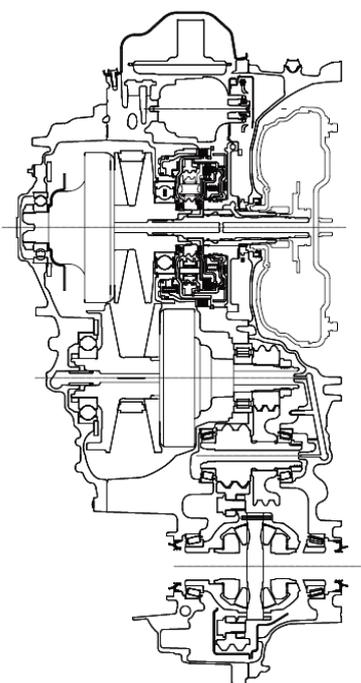


Fig. 1 Main cross-sectional view

Table 1 Specifications of JF017E

Torque capacity	350 Nm
Torque converter size	250 mm
Pulley ratios	2.413-0.383
Ratio coverage	6.3
Final gear ratio	5.250
Number of selector positions	4 (P, R, N, D) + Manual shift mode
Overall length	370mm
Weight (wet)	97.5kg

■ Typical model fitted with the JF017E CVT ■



Maxima

# スズキ向け ソリオ用 Jatco CVT7 (JF015E) の紹介

Introducing the Jatco CVT7 (JF015E) for the Suzuki Solio

2015年8月にスズキ株式会社より発売された新型「ソリオ」にJatco CVT7 (JF015E)が継続搭載されました。

副変速機付CVTのワイドな変速比幅により、レスポンスの良い発進と加速性能を確保しつつ、高速走行時の静粛性向上および低燃費を両立しています。また、小型車としては初のマイルドハイブリッド(ISG)対応でクラストップの27.8km/L (JC08モード)の燃費向上に大きく貢献しました。

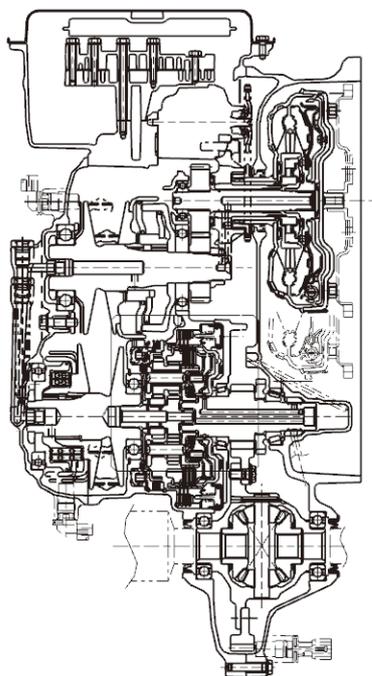


Fig. 1 Main cross-sectional view

The Jatco CVT7 (JF015E) continues to be mounted on the new-generation Solio released by Suzuki Motor Corporation in August 2015. Incorporating an auxiliary gearbox and featuring wide ratio coverage, the JF015E ensures a highly responsive vehicle launch and acceleration performance, while combining quietness during high-speed driving with better fuel economy. It contributes greatly to improving fuel economy, helping the Solio to attain class-leading fuel economy of 27.8 km/L under Japan's JC08 test mode. The Solio is Suzuki's first mild hybrid equipped with an integrated starter generator (ISG) system in the small car class.

Table 1 Specifications of JF015E

Torque capacity	118 Nm	
Torque converter size	185 mm	
Pulley ratios	2.200-0.550	
Auxiliary transmission gear ratios	1st	1.821
	2nd	1.000
	Rev	1.714
Ratio coverage	7.3	
Final gear ratio	3.882	
Number of selector position	5	
Overall length	349.2 mm	
Weight (wet)	64 kg	

■ Typical model fitted with the JF015E CVT ■



Solio

# 三菱自動車向け ミラージュ用Jatco CVT7 (JF015E)の紹介

Introducing the Jatco CVT7 (JF015E) for the Mitsubishi Mirage

2016年1月にタイを始め、欧州、日本でマイナーチェンジして発売された三菱自動車工業株式会社の「ミラージュ」に当社製Jatco CVT7 (JF015E)が継続搭載されました。

アイドルリングストップ機構「オートストップ&ゴー (AS&G)」に、コーストストップ機能を追加し、さらなる燃費性能向上に貢献しました。

また、CVTのクラッチ制御を改良し、駆動トルクを遮断することでアイドルリングストップ後のエンジン始動時の良好な発進フィーリングが実現でき、商品力向上に貢献しています。

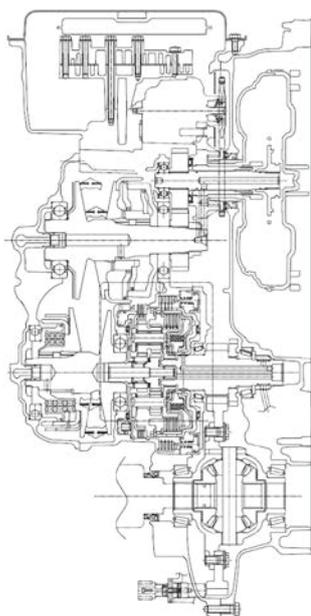


Fig. 1 Main cross-sectional view

The Jatco CVT7 (JF015E) continues to be mounted on the Mitsubishi Mirage that underwent a minor model change and was released in Thailand in January 2016, followed by rollouts in Europe and Japan.

The JF015E contributes to a further improvement in fuel economy with the addition of a coasting-mode stop/start function, which was added to the existing Auto Stop & Go (AS&G) system.

The clutch control of this CVT was also improved to provide a better start-off feel when the engine is restarted following activation of stop/start control. This is accomplished by cutting off the drive torque, and it contributes to improved product competitiveness.

Table 1 Specifications of JF015E

Torque capacity	106 Nm	
Torque converter size	205 mm	
Pulley ratios	2.200-0.550	
Auxiliary transmission gear ratios	1st	1.821
	2nd	1.000
	Rev	1.714
Ratio coverage	7.3	
Final gear ratio	3.882	
Number of selector positions	6 (P, R, N, D, Ds, L)	
Overall length	370.5 mm	
Weight (wet)	69.6 kg	

■ Typical model fitted with the JF015E CVT ■



Mirage



# ジヤトコ 一年間のトピックス

Highlights of the Past Year

## 1. ジヤトコメキシコツール事業開始，節目を迎えた ジヤトコツールが全面支援

1月15日、ジヤトコメキシコ(JMEX)にてツールビジネス部門のキックオフ式が行われた。日本企業が多く進出する現地アグアスカリエンテスでの工具研磨事業の需要に対応するため、ジヤトコツールが全面的に協力してJMEXの工具研磨事業部が外販を開始したものである。また、4月14日にはジヤトコツールは創立20周年を迎えた。「富士ツール」として創業した際には29名だった社員数は現在100名を超える規模となり、20年の間にジヤトコグループ以外へも販路を拡大し、グループ外への売り上げは現在約半分を占めている。



## 2. モーターショーへの出展

4月3日～12日に、韓国国際展示場で開催された「ソウルモーターショー2015」に出展した。韓国内に開発・営業拠点を持つ当社は2年に1度の開催時には毎回出展しており、今回で6回連続の出展となった。

また、4月20日～29日に、上海の国家会展中心で開催された「上海モーターショー2015」にジヤトコが初出展した。来場者数は約92万人にのぼり、当社ブースにも多数の来場者が訪れた。ブースでは、主力商品である「Jatco

## 1. JMEX launches tool business with all-out support from JATCO Tool, which celebrates a company milestone

JATCO Mexico (JMEX) held a kick-off ceremony for its tool business division on January 15, 2015. JMEX's tool sharpening division launched external sales with the full support of JATCO Tool Ltd, in response to the demand for tool sharpening service in Aguascalientes State where many Japanese companies are located. Moreover, JATCO Tool celebrated the 20th anniversary of its foundation on April 14, 2015. When it was established as Fuji Tool, the company had only 29 employees, but today the size of its workforce has grown to more than 100 employees. During the past 20 years, it has also expanded its sales channels outside the JATCO Group, and sales to customers outside the Group now account for approximately 50% of its annual turnover.



## 2. JATCO exhibits at motor shows

JATCO exhibited its products at the Seoul Motor Show 2015 held at the Korea International Exhibition Center from April 3-12, 2015. With engineering and sales offices in South Korea, JATCO has participated in this biennial motor show every event. This was JATCO's sixth consecutive time to present a booth at this event.

JATCO also exhibited its products for the first time at Auto Shanghai 2015 held at the National Exhibition and Convention Center in Shanghai from April 20-29, 2015.

CVT7」,「Jatco CVT8」やハイブリッド車用トランスミッション, 中国市場で販売している4速AT, 5速ATなどを紹介した。

さらに, 10月30日~11月8日に東京ビッグサイトで開催された「第44回東京モーターショー2015」にも出展した。「ジヤトコ・バリュー・エクスペリエンス」を展示ブースのテーマに設定し, CVT7, CVT8に加え, 初出展となる「Jatco CVT7 W/R」を展示するとともに, 将来のモビリティにおけるCVTのコンセプトを示す「CVTフューチャーコンセプト」と, VR(バーチャルリアリティ)技術を駆使した「CVTバーチャルドライビング」コーナーを設置し, CVTのメリットと可能性をさまざまなかたちで紹介し, 多くの来場者の関心を呼び, 好評を博した。



### 3. SAE学術講演会およびイベントへの参加

中国, 米国, 韓国, 日本で行われたSAE関連の春季大会, 秋季大会において計20件の学術論文発表を実施した。進化を続けるCVT技術ならびに制御技術に関する発表のほか, 生産技術の進化, CAE技術の進化等, 多岐にわたる技術領域におけるジヤトコの取り組みを紹介する発表を実施した。

また5月に同時開催のJSAE主催の「人とくるまのテクノロジー展」にも“進化を続けるジヤトコのCVT”をテーマに出展し, CVT7やCVT8などを展示したほか, 米国SAE大会, 中国SAE大会においても展示を実施した。

This motor show attracted some 920,000 visitors and large numbers of them visited JATCO's booth. Two of JATCO's leading products, the Jatco CVT7 and Jatco CVT8, were displayed at the booth along with a hybrid vehicle transmission as well as 4-speed and 5-speed automatic transmissions that JATCO markets in China, among other products.

Moreover, JATCO also presented a booth at the 44th Tokyo Motor Show 2015 held at the Tokyo Big Sight from October 30 to November 8, 2015. Under the theme of “JATCO Value Experience,” the JATCO booth displayed the Jatco CVT7 W/R in its debut exhibition, in addition to the CVT7 and CVT8. JATCO also presented its CVT Future Concept showing the concept of CVTs in future mobility and a CVT Virtual Driving exhibition that featured virtual reality technology. The advantages and potentialities of CVTs were presented in various forms, which attracted the strong interest of visitors and were highly acclaimed by them.



### 3. Participation in SAE Congresses and presentations of technical papers

JATCO employees presented a total of 20 technical papers at SAE conferences organized in the spring and autumn of 2015 in China, the U.S., South Korea and Japan. In addition to highlighting the ongoing evolution of CVT technologies and control technologies, these presentations also described JATCO's activities in a wide range of technical fields, including advances in production engineering and the progress of CAE techniques, among other subjects.

JATCO also presented a booth under the theme of “JATCO's continuously evolving CVTs,” at the 2015 Automotive Engineering Exposition organized by the



#### 4. CTIへの参加

5月20～21日にミシガン州のノバイでCTI USAが開催され、ジャトコメキシコ社長が「Contribution to the World Market by CVT Technologies」のPlenary Speechを行ったほか、技術講演で当社社員が「Advanced CVT control to achieve both fuel economy and drivability」の技術講演を行った。

9月16日～18日に開催された第4回CTI China シンポジウムでは、当社執行役員が「How to design market-specific transmissions for CHINA」、当社社員が「Evolution of a CVT with an auxiliary gearbox」の発表を行った。

12月7日～10日にベルリンで第14回CTIシンポジウムが開催され、当社役員が、昨今の自動車業界や顧客ニーズの動向の中でのお客さまの満足の実現に向けたジャトコのアプローチについての「More active for greater customer satisfaction」のPlenary Speechを実施したほか、新型CVTの概要「Development of new generation CVT with auxiliary gear box」とHEV用トランスミッションの混流ラインを紹介した「Advanced flexible production system for HEV CVT assembly」の技術講演を行った。



Society of Automotive Engineers of Japan, Inc. (JSAE) and held concurrently with JSAE’s annual spring congress in May 2015. The CVT7, CVT8 and other products were displayed at this event. JATCO also presented a booth at the SAE World Congress & Exhibition in the U.S. and at the SAE-China Congress & Exhibition.

#### 4. Participation in CTI Symposiums

The President of JATCO Mexico delivered a Plenary Speech entitled “Contribution to the World Market by CVT Technologies” at the CTI USA Symposium held in Novi, Michigan, on May 20-21, 2015. In addition, a JATCO employee gave a technical presentation entitled “Advanced CVT control to achieve both fuel economy and driveability.”

A JATCO executive gave a presentation entitled “How to design market-specific transmissions for China” at the 4th International CTI Symposium China held from September 16-18, 2015. A JATCO employee also gave a technical presentation entitled “Evolution of a CVT with an auxiliary gearbox.”

A JATCO executive gave a Plenary Speech entitled “More active for greater customer satisfaction” at the 14th International CTI Symposium held in Berlin from December 7-10, 2015. He explained JATCO’s approach to achieving customer satisfaction amid recent trends in the automotive industry and customer needs. In addition, JATCO employees gave technical presentations entitled “Development of a new generation CVT with an auxiliary gearbox,” which outlined JATCO’s newest CVT, and “Advanced flexible production system for HEV CVT assembly” that described JATCO’s mixed production line for conventional and HEV transmissions.



### 5. 新型「Jatco CVT7 W/R」出荷式

8月7日、ジヤトコ広州(JGZ)で新型Jatco CVT7 W/Rの出荷式が、JGZ社員約1100人と当社社長および専務、現地法人社長などの出席により行われた。この商品は世界初の副変速機付CVTとして2009年に登場したJatco CVT7の変速比幅を拡大し、中国における当社CVTの商品力をさらに強化する期待の新商品で、東風日産ラニアに搭載されて10月に発売された。(詳しくは本号の特集にて紹介)



### 6. JSAE主催 キッズエンジニアイベントへの支援

7月31日・8月1日に名古屋市中小企業振興会館で実施されたキッズエンジニア2015に当社も参加した。プログラム提供は全20団体で、2日間で5242名が来場した。当社は開催初年度からこのイベントを支援しており、「遊星ギヤってなんだろう?」の当社プログラムには約160名が参加した。



### 5. First shipment ceremony for the new Jatco CVT7 W/R

JATCO Guangzhou Automatic Transmission Ltd. (JGZ) held a ceremony on August 7, 2015 to mark the first shipment of the new Jatco CVT7 W/R. Attending the ceremony were approximately 1,100 JGZ employees, JATCO President and Senior Vice President, JGZ President and numerous guests. This product is the wide range version of the Jatco CVT7 that was launched in 2009 as the world's first CVT to incorporate an auxiliary gearbox. This new unit is expected to further strengthen the product competitiveness of JATCO's CVT lineup in China. It is mounted on the Lannia released by Dongfeng Nissan Passenger Vehicle Company in October 2015. (Further details about the Jatco CVT7 W/R are given in the special feature of this issue.)

### 6. JATCO supports Kids Engineering sponsored by JSAE

JATCO participated in Kids Engineering 2015 that was held at the Nagoya Trade & Industry Center on July 31 and August 1, 2015. Programs were presented by a total of 20 organizations, and 5,242 children and parents came to this two-day event. JATCO has been a supporter of this event since the first year it was held. Approximately 160 participants took part in JATCO's program entitled "What is a planetary gearset?"



## 7. JSAE主催 学生フォーミュラ大会を今年もサポート

9月1日～5日に小笠山総合運動公園(ECOPA)にて、第13回全日本学生フォーミュラ大会が開催された。

この大会は学生がチームを組み、約1年間でフォーミュラスタイルの小型レーシングカーを開発・製作し、走行性能だけでなく、車両のマーケティング、企画・設計・製作、コスト管理等のモノづくりにおける総合力を競う競技会で、今年是国内・海外から90チームが参加した。ジャトコとジャトコ エンジニアリングは、この競技会を支援し、社員による審査スタッフへの参加も行い、大会に貢献した。



## 8. VDIへの参加

6月16日・17日に独フリードリヒスハーフェンで開催されたVDI(ドイツ技術者協会)トランスミッションカンファレンスにて、当社社長が本会議講演(Plenary Lecture)を実施し、CVTのフレキシビリティで実現しているさまざまな技術と将来の可能性に言及した。また、技術発表では、当社社員がJatco CVT7に導入されたD-STEP(ダイナミックステップ制御)を紹介した。



## 7. JATCO again this year supports Student Formula Competition sponsored by JSAE

The 13th Student Formula SAE Competition of Japan was held from September 1-5, 2015 at the Ogasayama Sports Park (ECOPA). In this competition, student teams spend approximately one year developing and building a small Formula One style race car. The competition assesses their overall “monozukuri” capabilities, including marketing, planning, designing and manufacturing the vehicle, as well as cost management and other aspects, not just vehicle performance. This year 90 teams from Japan and abroad participated in the event. JATCO and JATCO Engineering Ltd provided support for this competition, and JATCO employees also contributed to it by serving as judges.

## 8. Participation in VDI conferences

JATCO President & CEO delivered a Plenary Lecture at the 14th International VDI Congress sponsored by Verein Deutscher Ingenieure (The Association of German Engineers) in Friedrichshafen, Germany, on June 16-17, 2015. He talked about various technologies achieved with the flexibility of CVTs and future possibilities. A JATCO employee also presented a technical paper describing the Dynamic Step Shift (D-STEP) control incorporated in the CVT7.

Two JATCO employees presented technical papers at the VDI International Conference on Gears held in Munich, Germany, on October 5-7, 2015. One of the papers was selected for the second prize of the Best Paper Award given to young engineers. This award was newly established at the 2015 conference for the purpose of developing young engineers and is targeted at engineers up to the age of 35.



10月5日～7日に独ミュンヘンで行われたVDIギアカンファレンスでは、当社から2件の技術発表を実施し、うち1件が、今大会から若手技術者の育成のために35歳以下のエンジニアを対象として設けられた若手技術者の優秀発表賞で2位入選を果たした。

### 9. ジャトコ広州主催のCVT大学セミナーを実施

8月5日・6日、ジャトコ広州(JGZ)において中国の大学生を対象とした、ジャトコCVT大学セミナーを実施した。今回で3回目となるこのセミナーには、パワートレインを研究している中国国内の有力5大学の教授と学生が19名参加した。

1日目には、業界の動向、CVTやHEVの概要、制御について講義を実施し、講義後にはCVTの分解実習や試乗会なども行った。2日目には、各大学の研究成果発表会を実施し、学生のみなさんと当社社員による活発な意見交換が行われた。

### 10. ジャトコプラントテックISO9001認証取得

9月25日、ジャトコプラントテックはISO9001 2008年版の認証登録を受けた。今後の海外への業務拡大を視野にいれ、その基礎となる品質マネジメントシステムを構築してきた成果が評価された。



### 9. JATCO Guangzhou sponsors the CVT University Seminar

JATCO Guangzhou Automatic Transmission Ltd. (JGZ) held the JATCO CVT University Seminar for Chinese university students at its plant on August 5-6, 2015. At this third seminar, 19 professors and students participated from five leading Chinese universities which are engaged in powertrain research. On the first day lectures were given concerning trends in the automotive industry, overviews of CVTs and HEVs and control technology, followed by hands-on training in dismantling a CVT, test drives and other activities. The second day was devoted to presentations of research results achieved at each university, and lively exchanges of opinions took place between the students and JGZ employees.



### 10. JATCO Plant Tec obtains ISO 9001 certification

JATCO Plant Tec Ltd received certification to ISO 9001:2008 on September 25, 2015. This evaluation attests to JATCO Plant's successful implementation of a quality management system as the basis for the envisioned expansion of its business overseas in the future.

## 11. ニスモフェスティバルへ参加

11月29日、富士スピードウェイで開催されたニスモフェスティバル(主催:ニッサン・モータースポーツ・インターナショナル)に当社も参加した。当社有志により、来場したお客さまにCVTや当社をより深く理解していただくために、スポーティな走行を楽しめるように特別なチューニングをしたCVTの試乗会と、実際のCVT組立員によるCVT分解組立ショーやからくり展示などのブース展示を実施した。



## 11. Participation in the NISMO Festival

JATCO took part in the NISMO Festival sponsored by Nissan Motorsports International Co., Ltd. at the Fuji Speedway on September 25, 2015. JATCO employee volunteers conducted a test-drive session using a CVT-equipped vehicle specially tuned for enjoying sporty driving. They also presented a booth where actual CVT assembly line workers showed how to assemble/disassemble a CVT, and various manufacturing improvements invented by employees were displayed, among other things. These activities were intended to give visitors a deeper understanding of CVTs and JATCO.



## 12. ジャトコメキシコ第2工場 ISO14001 認証取得

12月15日にジャトコメキシコ(JMEX) 第二工場 でISO14001の認証授与式が行われた。2014年9月の生産開始からわずか1年2ヶ月での認定取得であり、ジャトコグループとして最短での取得となった。

## 12. JATCO Mexico's No. 2 plant obtains ISO 14001 environmental management certification

JATCO Mexico (JMEX) held a ceremony on December 12, 2015 to celebrate the certification of its No. 2 plant to the ISO 14001 standard. The plant secured this certification in just 14 months since it launched production in September 2014. That is the shortest time for obtaining this certification within the JATCO Group.





# 特 許 紹 介

Patents

## 1. 車両の制御装置

(Fig.1,2)

出願番号 : 特願 2010-245721 号  
出願日 : 2010.11.1  
特許番号 : 特許第 5693151 号  
登録日 : 2015.02.13  
発明の名称 : 車両の制御装置  
発明者 : 明保能弘道, 山本英晴,  
三浦恒太, 斎藤恒

## 1. Control apparatus for vehicle

(Figs. 1 &amp; 2)

Application Number: 2010-245721  
Application Date: 1.11, 2010  
Patent Number: 5693151  
Registration Date: 13.2, 2015  
Title: Control apparatus for vehicle  
Inventors: Hiromichi Akebono,  
Hideharu Yamamoto,  
Kota Miura, Hisashi Saito

### 【発明の概要】

本発明の車両の制御装置は、クラッチをスリップ制御するとともに、クラッチの駆動源側の回転数がクラッチの駆動輪側の回転数よりも所定量高い回転数となるように回転数制御する走行モードと、駆動源の実トルクを検出するトルク検出手段を備えることを特徴とする。この構成により、走行モード中に車両停止状態と判定されたときは、指令油圧を初期指令油圧から低下させることで、低下に伴う駆動源の実トルク変化が終了したと判定したときの指令油圧を補正後指令油圧として出力することができる。

### 【SUMMARY OF THE INVENTION】

In control apparatus for a vehicle, the vehicle including a traveling mode in which a slip control is performed for a clutch and a revolution speed control is performed for the driving source such that a revolution speed at a driving source side of the clutch becomes higher than that at a driving wheel side of the clutch by a predetermined revolution speed, an actual torque of a driving source of the vehicle is detected, a command hydraulic pressure is reduced from an initial command hydraulic pressure and a post-correction command hydraulic pressure is set on a basis of the command hydraulic pressure when a variation in the actual torque of the driving source along with the reduction of the command hydraulic pressure is determined to end, when a vehicle stopped state is determined to occur during the traveling mode.

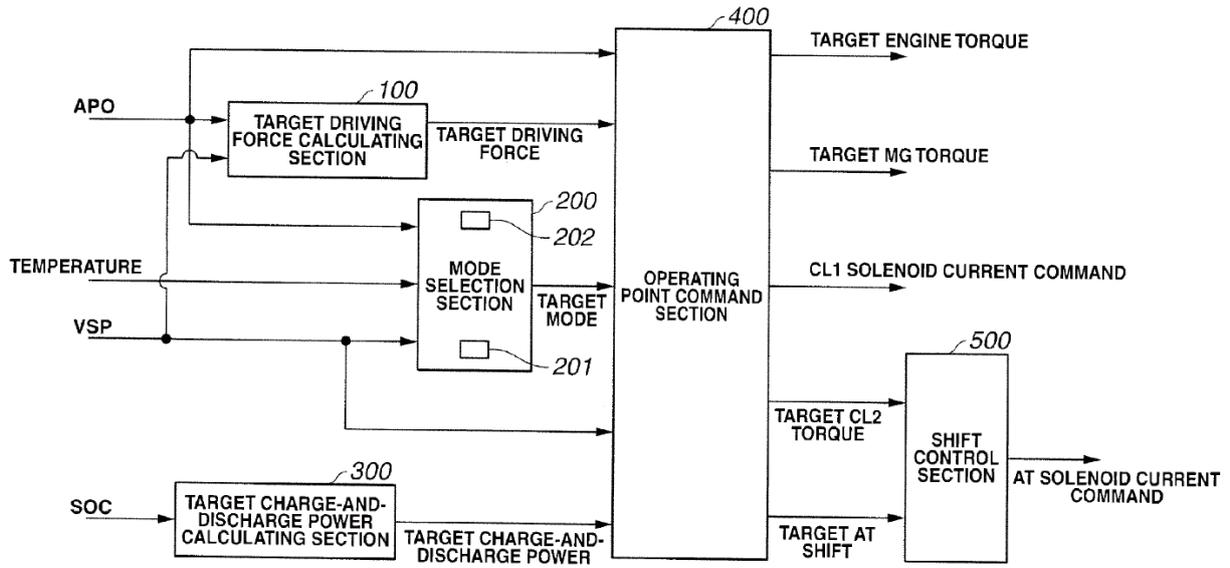


Fig. 1

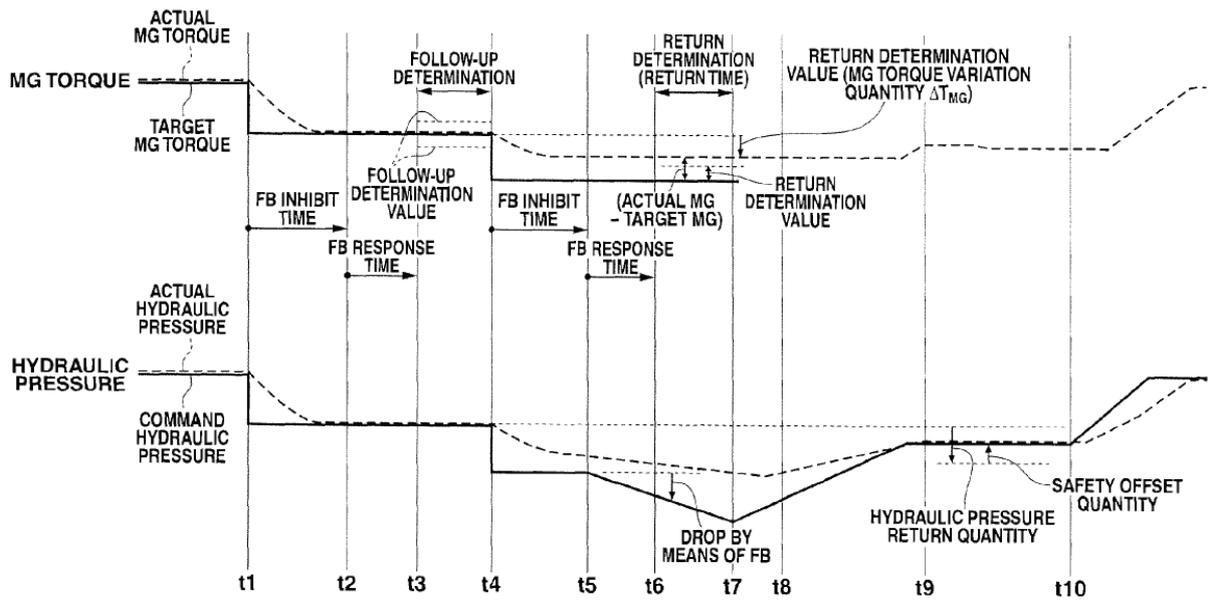


Fig. 2

## 2. コーストストップ車両

(Fig.3)

出願番号 : 特願 2010-223445 号  
出願日 : 2010.10.1  
特許番号 : 特許第 5646941 号  
登録日 : 2014.11.14  
発明の名称 : コーストストップ車両  
発明者 : 渡辺真一郎, 立脇敬一, 山田直弘,  
青山訓卓

## 2. Coast stop vehicle

(Fig. 3)

Application Number: 2010-223445  
Application Date: 1.10, 2010  
Patent Number: 5646941  
Registration Date: 14.11,2012  
Title: Coast stop vehicle  
Inventors: Shinichiro Watanabe,  
Keichi Tatewaki,  
Naohiro Yamada, Noritaka Aoyama

## 【発明の概要】

本発明の車両走行中にエンジン1を停止させるコーストストップ車両は、一対のプーリおよびこれらに掛け回されるベルトを有し、変速比を無段階に変更可能なバリエータを備え、コントローラが車両走行中にエンジンを停止させるコーストストップ条件の成否を判断することを特徴とする。この構成により、コーストストップ条件が成立すると、エンジンが停止され、コーストストップ制御中に変速比がコーストストップ制御開始時の変速比よりもHigh側へアップシフトすることが防止される。

## 【SUMMARY OF THE INVENTION】

A coast stop vehicle which stops an engine during the travel of the vehicle is provided with a variator including a pair of pulleys and a belt mounted between the pulleys and capable of continuously changing a speed ratio. A controller judges whether or not coast stop conditions to stop the engine during the travel of the vehicle hold, stops the engine when the coast stop conditions hold, and prevents the speed ratio from being upshifted to a higher side than a speed ratio at the time of starting the coast stop control during the coast stop control.

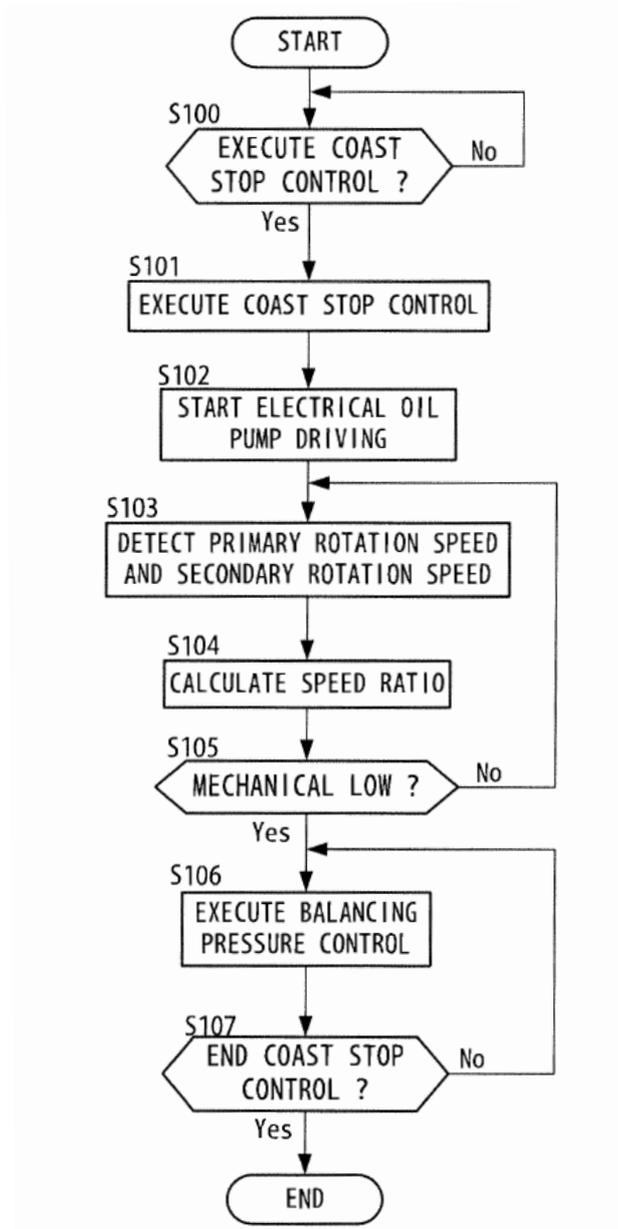


Fig. 3

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