Technical Trends in Constant Velocity Universal Joints and the Development of Related Products

Shin TOMOGAMI

Constant Velocity Universal Joints (CVJ) have come to be used widely for driveshafts and propeller shafts in vehicles, and are now being used for almost 100% of Japanese cars. CVJ performance has improved greatly with the evolution of vehicles. This paper will introduce recent technical trends and the development of products (parts) related to driveshaft CVJs.

1. Introduction

Forty-four years have already passed since NTN began production of the Constant Velocity Joint (hereinafter simply referred to as "CVJ"). The total number of CVJs produced thus far for driveshaft has nearly reached 400 million.

As Japan's auto industry has been expanding throughout this period, CVJs have been commonly used on driveshafts and propeller shafts of FF (Front-engine Front-drive) layout cars, IRS (Independent Rear Suspension) layout cars and 4WD (Four-Wheel Drive) layout cars. In today's market, virtually every passenger car designed in Japan incorporates the use of CVJs. The typical vehicle related areas in which the CVJs are applied have been illustrated in Figs. 1 and 2.

As automotive designs continually evolve, the performance of CVJs has been improved accordingly. This paper describes the technical trend about the recent driveshaft CVJs as well as newly developed CVJ products.

2. Current requirements for CVJs

Around the world, the global environmental issues (including global warming) have been posing challenges that need to be immediately addressed. Automobile manufacturers and their suppliers have been committed to various efforts including improved fuel economy, introduction of hybrid car design, use of bio-fuel and development of high-performance diesel engines in order to reduce emissions of CO₂ which is a major contributing factor to global warming.

As a result of these initiatives, CVJs as drive train-related components are required to feature a lighter weight and offer better torque transmission efficiency in order to help improve fuel economy on the vehicle.
In the next section, the author will present the history regarding weight reduction of driveshaft CVJs. Thereafter, the author will further explain functions, requirements and recent achievements about ball-fixed CVJ, plunging CVJs and CVJ components; each being a constituent of a driveshaft.

3. History of weight reduction for driveshaft CVJs

As the Holling-Kelly CAFE proposal seemed to be imposed in the US, the efforts for lighter weight component designs were strongly needed for every automotive manufacturer since the latter half of the 1980’s. To cope with this need, NTN has been committed to light-weight, compact designs for its driveshaft CVJs with its unique technologies.

In the early 1990’s, NTN developed a high-strength material and a long-life lubricant (grease) to realize a lighter-than-ever driveshaft CVJ. As a result of this effort, a lighter weight arrangement was achieved, whereas a CVJ of one nominal size smaller relative to a CVJ previously used on a given vehicle size could be employed.

In a time span from 1998 to the earlier half of 2000, NTN developed and mass-produced the next-generation CVJ products (E-series CVJ) that are much more compact compared with the previous CVJ series products, in order to meet the needs from the automakers. The change in size and weight with a typical CVJ (87 size) is graphically plotted in Fig. 3. Compared with weight levels in 1990, the weight of the present-day ball-fixed CVJ is 23% lighter while that of the present-day plunging CVJ is 17% lighter.

4. Ball-fixed CVJs

4.1 Functions of ball-fixed CVJs

A ball-fixed CVJ used on a front driveshaft of an FF or 4WD layout car is coupled to the front wheel hubs on a vehicle. This application results in a working angle while the steerable tires change the running direction as the steering wheel is operated, thereby transmitting the driving power from the engine to the tires while smoothly running at a constant velocity. Additionally, a ball-fixed CVJ directly affects the unsprung weight of a vehicle suspension.

4.2 Needs for ball-fixed CVJs

A need for a smaller turning radius with a vehicle, that is, a need for a greater steering angle with front wheels, has been significantly increasing as the recent car designs involve longer wheel bases and more diversified drive train layouts. In this context, a greater working angle is needed for ball-fixed CVJs whose working angles are governed by the steering angle of front wheels. Previously, the maximum working angles needed for ball-fixed CVJ were at approximately 47 degrees. However, larger working angles with ball-fixed CVJs on many car designs are currently needed with a (maximum working angle of up to 50 degrees).

At the same time, decreasing the weight of the car is necessary in order to help improve fuel economy, and under this circumstance, lighter CVJs are strongly needed. In particular, because of being situated near the tires, ball-fixed CVJs contribute to the unsprung weight of a vehicle. Therefore, a decrease in the weight of these CVJs positively contributes to a decrease in the overall vehicle weight.

![Fig. 3 Transition of outer diameter and weight of CVJ (Example of initial 87 size)](image-url)
Generally, it is said that the effect by a decrease in unprung weight is approximately 10 times effective as a decrease in sprung weight. Thus, lighter CVJs will greatly help improve fuel economy of the vehicles.

### 4.3 Latest ball-fixed CVJs

As the needs from car designs continue to evolve, the typical ball-fixed CVJ products that are currently used on the front driveshafts of FF cars and 4WD cars are matched with reduced size (compact) and lightweight joints with a maximum working angle of 50 degrees.

NTN offers a full lineup of the "EUJ series" compact, lightweight CVJs with a maximum working angle of 50 degrees for cars ranging from small-displacement engines to that of larger SUVs (Sports Utility Vehicles).

Compared with conventional 50-degrees working angle capable CVJ designs, the "EUJ" series products boast approximately 7% reduction in the outside diameter and approximately 15% reduction in the weight (Photo 1).

Furthermore, the EUJ series products are lightweight, high-efficiency eco-friendly CVJ products that feature 25% reduction (working angle of 6 degrees) in the loss in driving force (torque loss) transmitted from an engine to the tires (Fig. 4).

NTN additionally offers a lineup of the "EBJ series" with a maximum working angle of 47 degrees intended for vehicles on which the maximum working angle needed is less than 47 degrees. Compared with the "EUJ", the EBJ ball-fixed CVJ products feature a 3% smaller outside diameter and a 7% lighter weight while maintaining the high efficiency and performance of the EUJ series CVJs.

An automobile manufacturer can choose to use either an EUJ or EBJ product according to the maximum working angle needed by an intended vehicle design.

### 4.4 Vibration reducing techniques for ball-fixed CVJs

It is said that a plunging CVJ in a driveshaft affects the NVH (Noise, Vibration and Harshness) performance of a vehicle. Additionally through research, it has been determined that the characteristics of a ball-fixed CVJ also affects the NVH performance of a vehicle.

In particular, reducing the bending load (resistance occurring when a CVJ takes a working angle) on a ball-fixed CVJ can dampen the idling vibration on the vehicle. "Idling vibration" can be defined as minute vibration that is transmitted from the running engine to the vehicle body through the CVJ when the footbrake on an automatic transmission vehicle (A/T car) at a temporary stop is applied while the transmission is in a drive gear.

NTN achieves reduction in the bending load of its ball-fixed CVJs through optimization of the internal component design and dimensions (Fig. 5, Photo 2).

[![Fig. 4 Measurement data of torque loss for compact & light weight fixed CVJ (EUJ)](image)](image)

[![Photo 1 Compact & light weight fixed CVJ with 50 degree working angle (EUJ)](image)](image)

[![Photo 2 Less idling vibration CVJ](image)](image)
5. Plunging CVJs

5.1 Functions of plunging CVJs

Being coupled with a differential, a plunging CVJ transmits the driving power from an engine and a transmission to tires via a ball-fixed CVJ. A plunging CVJ is capable of absorbing the change in position relative to a ball-fixed CVJ that results from move of the suspension (axial displacement and angular displacement).

5.2 Requirements for plunging CVJs

It is widely known that the characteristics of any plunging CVJ affect the NVH characteristics of a given vehicle. Axial plunging resistance, which occurs when a plunging CVJ vibrates in the axial direction, is responsible for idling vibration of the vehicle. In addition, the axial force (known as "induced thrust") occurs on a plunging CVJ when the CVJ takes a working angle and runs while being subjected to a driving force. This force can contribute to a jerking phenomenon when the vehicle starts to travel as well as produce howling sound while the vehicle is running at a higher speed.

Therefore, plunging CVJs are required to have lower plunging resistance lower induced thrust and incorporate weight reduction design characteristics.

5.3 Latest plunging CVJs

To cope with recent needs for improved quietness and riding comfort with vehicles, CVJ manufacturers are developing a diversity of plunging CVJ designs. Having developed an ultra low vibration plunging CVJ "PTJ" that boasts greatly reduced plunging resistance and induced thrust, NTN products contribute to improved NHV performance of vehicles.

Our "PTJ" is a tripod type plunging CVJ design, wherein three roller cassettes (each being a special roller bearing) are situated inside the outer ring that is coupled with the differential. Moreover, the roller cassettes can stably roll on the rolling surface of the outer ring when the CVJ develops a working angle and/or axially plunges. This arrangement helps reduce the plunging resistance and internal friction so as to achieve ultra low vibration (Fig. 6).

Our ultra-low vibration CVJ products excel in transmission efficiency for driving force (torque). When combined with the previously mentioned EUJ and EBJ, the PTJ will help minimize the torque loss on the driveshaft into which it is incorporated.

5.4 Ultra-low vibration CVJ of compact & lightweight design

To satisfy the market needs, NTN has commercialized compact, light-weight ultra-low vibration "EPTJ" series CVJ products that feature a structure and low vibration characteristics identical to that of the ultra-low vibration "PTJ" series CVJs. Further compared with the PTJ, the EPTJ boasts approximately 4% reduction in outside diameter and approximately 8% reduction in the weight. NTN offers the EPTJ series products for larger CVJs (NTN nominal size 95 or greater) with which a lighter weight provides many advantages (Photo 3).

![Photo 3 Ultra low vibration CVJ with compact & lightweight design (EPTJ)](image)

![Fig. 6 Structure of ultra low vibration plunging CVJ (PTJ)](image)

[Mechanism of ultra-low vibration arrangement]

The roller cassettes are held parallel with the rotation axis and stably roll on the rolling surface of the outer ring, thereby the friction force between parts is minimized so as to achieve ultra-low vibration.
6. CVJ components

6.1 Requirements for CVJ components

The requirements for CVJ components relative to the vehicle include lighter weights and enhanced rigidity (stiffness) against torsion on driveshafts. Greater rigidity on a drive system with CVJs will positively improve driver’s feeling while maneuvering the vehicle. Therefore, highly rigid CVJ components are strongly needed especially for sporty and/or luxury passenger vehicles.

6.2 Latest technology with CVJ components—hollow design

A lighter, more compact component usually has lower rigidity. This is true with the components of CVJs too. In particular, rigidity is greatly affected by the shape of a shaft that connects a ball-fixed CVJ to a plunging CVJ. A recently available technology that satisfies conflicting requirements of lighter weight and higher rigidity is a hollow shaft design. A few examples of this technology are introduced below.

6.3 Hollow design—application to shaft

A shaft links a ball-fixed CVJ with a plunging CVJ to transmit engine torque to the wheels. Conventionally, a solid bar made of carbon steel for machinery is heat-treated and is used as a shaft (Fig. 7). Compared with the CVJs (both ball-fixed and plunging CVJs), the shaft typically has lower torsional rigidity. Therefore, it is an effective arrangement to increase the rigidity of the shaft in order to enhance the torsional rigidity of the entire driveshaft.

Reiterating that a larger diameter leads to increased rigidity of the shaft, one must also note that this arrangement in turn results in a much greater shaft weight.

Therefore, in order to realize both lighter weight and higher rigidity, a shaft being hollow over its entire length may be used (Fig. 8).

6.3.1 Features of hollow shaft

A length of steel pipe such as a one shown in Fig. 9 is swaged with a special machine (metal forming) to control the outside and inside diameters of the shaft while reducing the overall shaft diameter, whereby a hollow shaft is then formed.

Next, the hollow shaft is heat-treated (induction hardening, etc.) to increase its mechanical strength.

Upon completion of this unique design process, the hollow shaft can be up to 20 to 30% lighter compared with a conventional solid bar shaft whose torsional rigidity is equivalent. Additionally, a hollow shaft design also boasts increased bending rigidity, and thus can dampen the vibration resulting from bending resonance on the shaft.

6.4 Hollow design—application to plunging CVJ

With a transverse engine layout such as those on FF layout cars, the differential is offset relative to the centerline of the car. Consequently, the length of the right half of the driveshaft differs from that of the left half. With certain designs of driveshafts used on this type of car layout, the right and left stems to be installed to the differential of the plunging CVJ each have a unique length so that the length of the right half of the driveshaft is same as that of the left half of the driveshaft (equal shaft length design). With this arrangement, the working angle of the ball-fixed CVJ is same with the plunging CVJ on each of the right half and left half of driveshaft. As a result, the vehicle boasts better driving stability; therefore, an equal shaft length design is adopted for many FF and FF based 4WD vehicles.

With an equal shaft length design, the stem on the
Right or left plunging CVJ is 20 to 30 cm longer compared with the other plunging CVJ and is of the solid stem type. If sufficient torsional rigidity is to be provided for a given driveshaft, the diameter on this longer stem section needs to be larger, and the resultant increased weight of this section leads to a heavier overall weight with the entire driveshaft assembly (Fig. 10).

6.4.1 Plunging CVJs with hollow stem

According to our new technology, a length of steel pipe is incorporated as an intermediate section for the stem between the plunging CVJ main body (outer ring) and the differential in order to realize an integrated structure (Fig. 11). The mechanical strength of this steel pipe section is increased by optimizing its composition and machining method; the outside diameters of the steel pipe and joints are sufficiently large and the steel pipe is not heat-treated.

With the shown example hollow driveshaft, the stem (having torsional rigidity same as with the solid plunging CVJ outer ring) is 0.8 kg (approximately 17%) lighter compared with the solid design.

7. Eco-friendly CVJs

Car manufacturers are committed to design and manufacture of "eco-friendly cars". In this context, we have been making efforts not only to design compact, light-weight and highly efficient CVJs that contribute to better fuel economy but also to eliminate any environmentally unfriendly chemicals or substances from the materials used to make our CVJ products.

In terms of eliminating environmentally unfriendly chemicals and substances, we have already eliminated grease containing lead, and paint with lead-free materials, and have adopted hexavalent chromium-free plated components instead of previous hexavalent chromium-plated components.

Additionally, in the latest CVJ production process at NTN, we employ a unique dry cutting process instead of the previous wet grinding process that uses a grinding wheel.

The previous wet grinding process required a large amount of coolant (oil-based and/or water-soluble cutting fluid), which must be renewed and appropriately disposed at regular intervals. The dry cutting process does not need any such coolant. These are just some of the examples regarding NTN's commitment to reduction in environmental impacts.

8. Afterword

This paper has presented some examples of NTN's latest technology for driveshaft CVJs. Performance of automobiles improving. Functions and performance of constant velocity joints are directly or indirectly contributing to this performance improvement. As a specialist in constant velocity joint production, NTN is committed to developing and supplying constant velocity joint products that contribute to the progress of automobiles and are friendly to the global environment.

References
1) Tomoue: Latest technology trends for constant velocity joints, Tribology Monthly, No.218, pp.49-51 (2005)