POSSIBILITIES OF USE AND CHARACTERISTICS OF HIGH-PRECISION TRANSMISSIONS IN MACHINERY

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The application and use of gear mechanisms in machines is now widespread in all industrial areas. With the development of science and technology, especially in the field of control and management of movements of executive members of technological equipment, the requirements for the accuracy parameters of transmissions in the drives of machinery are growing. This applies to parameters specified as torsional stiffness, reduction ratio, lateral play, play. High-precision reduction gears are precise, efficient and provide high-quality gears that are cost-effective, quiet and provide high performance. The term high-precision gears comes mainly from their manufacturers, especially Japanese companies such as Teijin Seiki, Sumitomo Cyclo, and the Slovak company Spinea also belongs to them with its parameters. From the point of view of development and research, these transfers can be classified as promising transfers.

KEYWORDS

high-precision gears, zero backlash gearbox, gearing, cycloid gearbox, reducer, kinematic accuracy.

1 INTRODUCTION

With the development of science and technology in various industries, the requirements for the accuracy of the transmission mechanisms used in the drives of machines and machinery are constantly increasing. A compact device that posses both superiorly accurate reduction gear as well as radial-axial is designated as "High precision reduction gear". In general, they are characterized as gears manufactured with very high precision, especially their functional areas with tolerances of the order of about 1 µm [Spinea 2019, Sumitomo Fine Cyclo 2019, Teijin Seiki 2019]. These gears are meant for usage that require a high reduction ratio, high kinematic accuracy, low lost motion, maximum moment capacity and elevated rigidity of a concise pattern with a constrained fitting zone, lowered mass. Depend on high resistance and over-load limit of reduction gear is incorporated with radial-axial bearing. Thus, it helps in saving of maintenance costs during whole usage time of high precision reduction gear.

These high precision gears addresses a joining of high load conveying reduction gear with unique reduction component and high load conveying output bearing into one concise unit. Small dimensions and indispensable mix of first-class parameters lead to high utility worth in an optimum ratio of performance, measurement and cost.

The significant benefits of a high precision reduction gears are [Spinea 2019, Sumitomo Cyclo 2019, Teijin Seiki 2019]:

- zero-backlash reduction gears
- high-moment capacity
- excellent positioning accuracy and positioning repeatability
- high torsional and tilting stiffness
- small dimensions and weight
- high reduction ratios
- high efficiency
- long lifetime
- easy assembly

This new transmission concept allows using the reduction gear in state-of-the-art mechanics and robotics, gadget tools, measuring equipment, navigation, aircraft industry, army and medical field, carpentry field, printer's branch, machines for textile industry and glass treatment, filling machines, and so forth.

A participating representative of these transmissions is a reducer operating on the cycloidal principle of motion transmission from the input and output members of the reducer. Due to their own design of these reducers (eg TWIN SPIN, TEIJIN SEKI), some manufacturers also call their reducers the "bearing" attribute. The name bearing reducer is derived from the design of this reducer. It expresses the full integration of the transmission and the radial-bearing bearing in one unit.
In the current technical-technological practice, by increasing the quality and quantity of production, it is possible to observe, despite some fluctuations in economic development, a constant gradient of increasing requirements for the quality and precision of production, handling equipment, special-purpose equipment, equipment in the healthcare sector, etc. There are several areas (Fig. 1) where these high-precision transmissions or their accuracy parameters are required at their stability and where their application is prospectively assumed. The first area is high-quality machine tools and machining centers, single-purpose and modular machine tools.
Another prerequisite for the use of high-precision transmissions is welding positioners in automatic production, also in the field of aviation and military technology. These gears are further applied to in the of handling and robotic devices, further in transport and handling systems. Prospective possible application is in textile machines and in a relatively wide area of aviation and military technology. Another current application is in patient irradiation facilities.

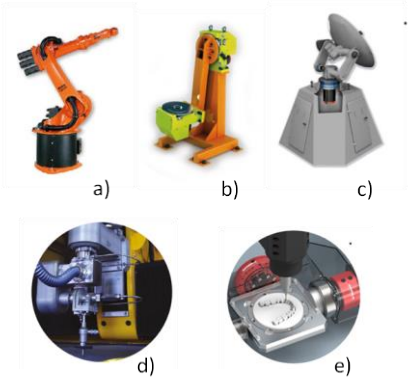

Figure 1. Areas of application of high-precision gears: a) robotics, b) automation and service robotics, c) navigationand security, d) machine tools, e) medical equipment.

2 ZERO BACKLASH

High-precision gears are characterized as backlash-free gears.
The clearance (Fig. 2) is the gap between the trailing edge of the energy-transmitting tooth and the immediately following

trailing edge. Clearance is not to be confused with th flexibility or torsional rigidity of the system. [Robotics 2015]. The general purpose of the play is to prevent the gears from jamming during simultaneous contact on both sides of the teeth. A small amount of clearance is required to provide space for lubricant and differential expansion between transmission components. The clearance is measured on the output shaft in the last gear.

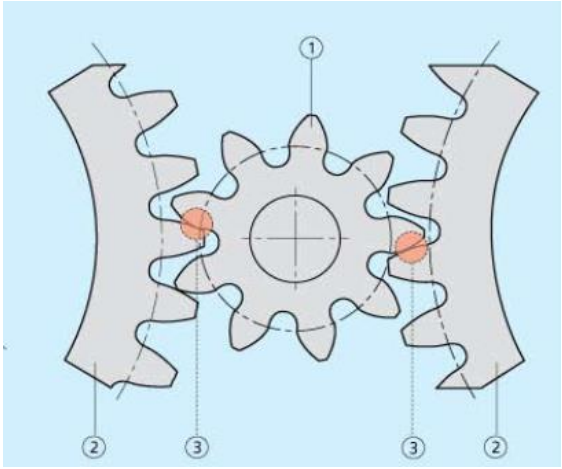

Figure 2. Zero Backlash: 1 - pinion, 2 - wheels, 3 - zero play

There are several ways in which it is possible to provide a gearbox with zero backlash, thus enabling high precision motion control.

Is a wide range of modification techniques [Rozum Robotics 2015], but the most commonly used are as follows:

Decreasing the width between centers - smaller between-center distances are achieved either by securing a gearwheel in place with preset spacing or by inserting a spring. Rigid bolted assembly is typical of bidirectional gearboxes of the bevel, spur, worm or helical type in heavy-duty applications. Spring loading is a better choice to keep lash at acceptable values in low-torque solution.

Splitting - the split arrangement implies mounting two halves of a gearwheel [Monkova 2019, Patel 2021] onto a shaft side by side with a spring [Krajnak 2021] in between. One half is secured in place, while the other is forced to turn slightly by the spring. The technique is commonly used in systems where speeds and loads are low.

Preloading - to eliminate the clearance between the interfacing teeth, a torsion spring or a load is coupled to the last driven gearwheel. The technique proves especially efficient in multi-stage applications, where play is a cumulative magnitude. Those are typically low-torque engines rotating in one direction only. The biggest issues with the configuration is that the preloading impairs free spinning. To eliminate the problem, it is advisable to replace them with an auxiliary motor.

Dual-path configuration - In the configuration, two identical gearing sets are mounted in a parallel arrangement and gyrate in opposite directions. Additionally, the arrangement is preloaded: a motor shaft is inserted together with a pinion into the gearhead. The downsides are doubled quantity of components and extended assembly time.

3 CHARACTERISTICS OF TWINSPIN REDUCER

TwinSpin high precision reduction gears are designed for applications requiring a high reduction ratio, high kinematic accuracy, low lost motion, high moment capacity and high stiffness of a compact design with a limited installation zone, and low mass.

The transmission and drive by means of the TWIN SPIN gearbox [Spinea 2019] is realized via an input high-speed member, which in this case is an input, solid or hollow shaft. The input shaft includes two eccentrically ground bearing tracks, on which the gear wheels are located in roller bearings. The wheels engage their modified parts via prestressed linear roller guides with the respective surfaces of the transformer members. The inlet and outlet flanges are firmly connected to each other and rotate at a reduced speed in a radial-axial outlet bearing relative to the body. Radial-axial bearings are very precise bearings mounted with preload - without play (Fig.3). They capture external forces and moments prectically in all directions.

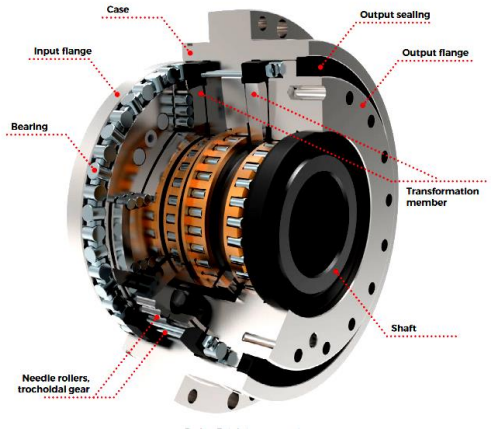

Figure 3. Characteristics of TWINSPIN REDUCER

TwinSpin reduction gear is an exclusive solution. The term “TwinSpin" suggests the overall assimilation of a high precision trochoidal reduction gear and a radial- axial bearing in a one compact unit. This new transmission conception permits the usage of TwinSpin reduction gear immediately in robotic joints, rotary tables, and wheel gears in diverse transport systems. Twinspin devices are High precision reduction gear and high precision radial-axial bearing in a compact unit [Spinea 2019, Spinea 2018]. These are of five distinctive types, namely – T series, E series, H series, M series and G series.

Series	A	B	C	D	E	F	G
T	XXX	XXX	XXX	XXX	XXX	XX	XXX
E	XXX	XXX	XXX	XXX	XXX	XX	XXX
H	XXX	XXX	XXX	XX	XXX	X	XXX
M	XXX	XX	XXX	XXX	XXX	XXX	XXX

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A - Rated output torque, B - Tilting stiffness, C - Torsional stiffness, D - Motor assembly, E - Radial-axial run-out, F -No-load starting torque, G - Lost motion

Table 1. Overview of the high precision reduction gear versions

3.1 Series angular transmission accuracy

With angular transmission accuracy, the angular transmission deviation on the output shaft is determined at its one revolution between its theoretical constant value and the

actual vibrations around its mean value. The angular error of the TwinSpin high-precision gear unit is usually 1 angular minute or less [Spinea 2019] Fig. 3. shows example of a gear angular error measured on a specific TwinSpin® TS 140-139-TB reduction gear.

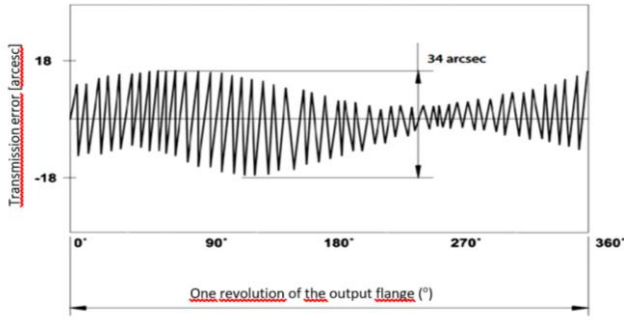

Figure 4. Angular transmission error measurement

4 CHARACTERISTICS OF ACCURACY OF REDUCERS TEIJIN SEIKI

The products of this company are included among high-precision gears. They work similarly to TWIN SPIN reducers on the principle of cycloidal engagement of gear teeth with internal gear teeth of the housing, which represent needle-shaped rollers evenly distributed on the inner side of the gearbox body. From the point of view of the design principle [Teijin seiki 2016] represent an epicyclic reduction mechanism that has an effect in the low moment of inertia and optimizes the vibration characteristics. These reducers allow high acceleration and have great accuracy in the possibility of output movement. The transmission of speed from the input shaft to the output is carried out via input gears driving the camshafts located in bearings around the circumference around the input shaft.

TEIJIN SEIKI [Teijin seiki 2019, Teijin seiki 2016] manufactures reducers in three basic types "RV", "RD", and "RH". All three types have essentially the same principle of motion transmission resp. power from the input member of the shaft to the output member, which is either the shaft connected to the output flange or the gearbox body itself. It is to be noted that RV (Fig. 5) is a 2 - stage precision reduction gear.

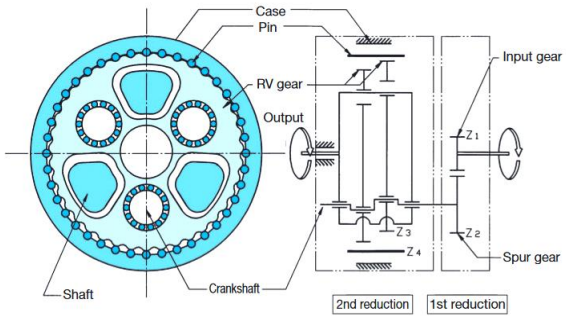

Figure 5. Kinematic principle of the reducer

4.1 Basic properties of high precision reduction gears TEIJIN SEIKI

The accuracy of TEIJIN SEIKI reducers can be assessed according to similar characteristics given by the manufacturer as for TWIN SPIN reducers.

The basic characteristics of accuracy are: torsional rigidity, lost motion, side clearance, torsional vibration and angular transmission error. When a torque is carried through the output shaft whilst the input shaft (input gear) is fixed, torsion is generated in line with the torque value and a hysteresis curve result is shown in Fig. 6 [Teijin seiki 2019, Teijin seiki 2016].

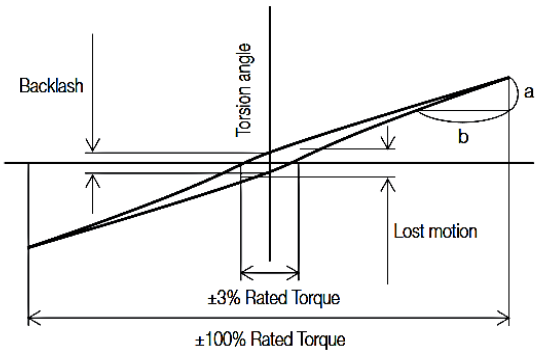

Figure 5. Dependence of torsional stiffness, backlash and hysteresis play on torsional angle

The external load moment may be applied to the reduction gear during normal operation. The allowable values of the external moment and the external axial load at this time are each referred to as allowable moment and maximum thrust load. The angular transmission error is defined as the difference between the theoretical output angle of rotation (when there are input instructions for an arbitrary rotation angle) and the actual output angle of rotation Fig. 7 [Teijin seiki 2019].

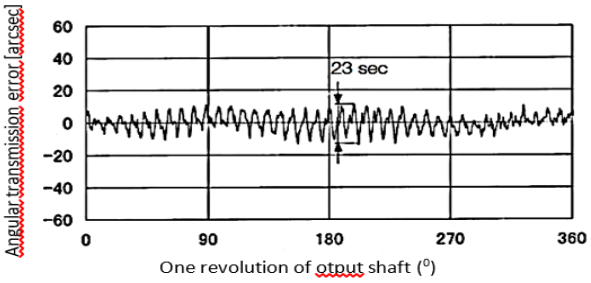

Figure 7. Representation of the error of the angular gear at the reducer

5 DESIGN OF HIGH PRECISION REDUCTION GEARS - SUMITOMO FINE CYCLO

The Fine Cyclo line of precision gearboxes from Sumitomo Drive Technologies [Sumitomo Cyclo 2019]. Was developed for the most demanding applications. All Fine Cyclo [Kumar 2015] gearboxes offer zero mechanical backlash ideal for the robotics, machine tool, medical, and general automation industries. Their high torque density allows for maximum torque in compact spaces. Sumitomo Drive Technologies developed these highly accurate gearboxes with high torsional stiffness with a low mass moment of inertia – making them ideal for highly dynamic tasks. These gearboxes come fully sealed and greased for life. Providing a maintenance-free solution for applications ranging from 100 Nm to 30,000 Nm.

There are essentially four major components in the cyclo gearbox.

a - High speed shaft with eccentric bearing.

b - Cycloid disc.

c - Ring gear housing with pins and rollers.

d -Slow speed shaft and flange wits pins and rollers

As the eccentric rotates, it rolls one or more cycloid disc around the internal circumference of the ring gear housing. The resulting action is similar to that of a disc rolling around the inside of a ring. As the cycloid disc travel in a clockwise path around the ring gear, the discs themselves turn in a counter-clockwise direction around their own axes. The teeth of the cycloid discs engage successively with the pins of the fixed ring gear, thus producing a reverse rotation at reduced speed. The reduction ratio is determined by the number of cycloid teeth on the cycloid disc. There is at least 1 lass tooth per cycloid disc than there are rollers in the ring gear housing which results in the reduction ratio being numerically equal to the number of teeth on the cycloid disc [Sumitomo 2019, Kumar 2015]. Therefore for each complete revolution of the high speed shaft the cycloid disc move in the opposite direction by one tooth .

Operating principle series A, D, and C - the gearbox of the Fine Cyclo series is fundamentally different in principle and mechanism from the helical gearing mechanism of competitors' gear motors. The unique reduction gearbox is an ingenious combination of the following two mechanisms:

- planet gear and a fixed internal sun gear (hollow gear). On the Fine Cyclo the planet gear has cycloidal cam motion and the fixed sun gear has a circular arrangement of ring gear pins. The fixed sun gear has one or two teeth more than the planet gear
- spline for constant speed.

The Series T gearboxes are double stage and differ from the single stage series in having 3 eccentrics, driven by the input shaft with spur teeth. The cycloid discs are driven via 3 eccentric shafts and not directly by one eccentric input shaft Fig. 8 [Sumitomo Fine Cyclo 2019].

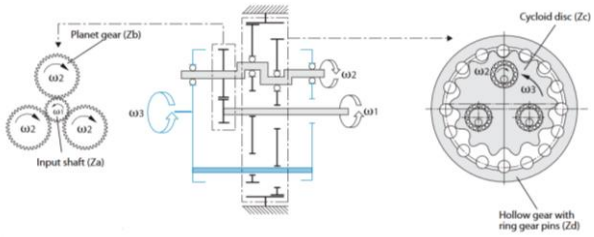

Figure 8. Duble stage gearbox SUMITOMO FINE CYCLO

The backlash is evaluated as the angular deflection of the output shaft when iis loaded from zero value ± 3% of the torque from the nominal torque - Fig. 9 [Sumitomo Cyclo 2019].

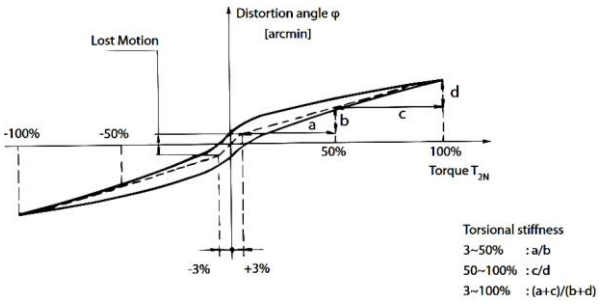

Figure 9. Dependence of torsional stiffness and backlash on the torsion angle of the output shaft.

6 COMPARISON OF HIGH – PRECISION TRENSMISSION REDUCTION TWINSPIN, TEIJIN SEIKI AND SUMITOMO FINE CYCLO

The graph (Fig. 10) shows the torsional stiffness of TWINSPIN, TEIJIN SEIKI and SUMITOMO FINE CYCLO µm reducers [Spinea 2019, Sumitomo Fine Cyclo 2019, Teijin Seiki 2019] depending on the speed and output torque, high stability of repeated accuracy.

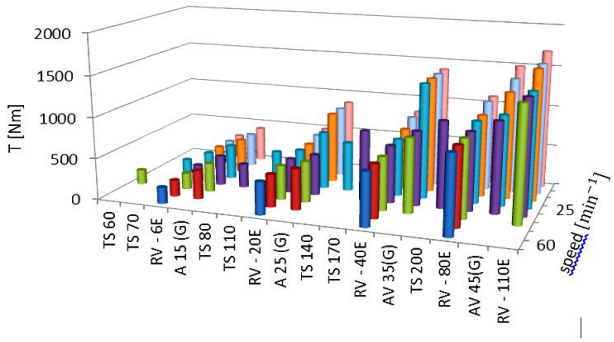

Figure 10. Comparison of torsional stiffness up to 400 Nm / min depending on the transmitted torque T and speed n for individual types of high-precision reducers.

An illustrative comparison of the decisive parameters of the analyzed reducers according to manufacturers [Spinea 2019, Sumitomo Fine Cyclo 2019, Teijin Seiki 2016] is provided by the following Table 2.

Type	Transmitted powerP [kW]	Output torque T_2 [Nm]	Torsional stiffness [Nm/min]	Revolutions at the input n_1 [min^{-1}]	Revolutions at the output n_2 [min^{-1}]	Transmission ratio u	Dead motion – angle [´]	Dimensions Ø x L [mm]
TwinSpin TS 60 up to TS 300	0,5 ÷ 10	37 ÷ 2 940	3,7 ÷ 720	1 500 ÷ 2 000	10 ÷ 65	33 ÷ 191	1´	Ø63 x 40 ÷ Ø300 x 113
Teijin Seiki RV – 6E up tp RV-450E	0,07 ÷ 13,8	101 ÷ 7 497	20 ÷ 1 176	150 ÷ 9 180	5 ÷ 60	27 ÷ 192,4	1´	Ø122 x 92 ÷ Ø370 x 160
Sumitomo Fine Cyclo A 15 (G) up to A 75(G)	0,65 ÷ 16,1	111 ÷ 5 450	4,5 ÷ 3 900	600 ÷ 4 000	8 ÷ 50	29 ÷ 179	2´	Ø115 x 57 ÷ Ø310 x 131

Table 2. Decisive parameters of accuracy, performance and dimensions of the compared reducers

All three types of reducers have a similar principled way of transmitting satellite motion to centric motion with similar links. In addition to the positive properties, their disadvantages were also identified during the analysis. Disadvantages are associated with the complexity of the solution of satellite motion transmission to centric, the need for precise assembly with adherence to precise tolerances and the resulting possible losses, limited load capacity and liveliness. An illustrative comparison of the characteristics of the reducers is given in Table 3.

Name	Characteristics	Performance	Features	Application	Principle of Operation	Design
TwinSpin	Easy implementation and excellent tilting and torsional stiffness parameters, a trouble-free operation with exceptionally low noise and vibrations	-high torque and long life -it has high tilting stiffness -it is known for low friction -it is a high precision output bearing -high torque -density -reduced lost -motion settings	Unique torchoidal profile with high tilting stiffness.	Robotics, Machine tools, Automation & service robots, Medical equipments, Radars, navigationequipment, safety and army devices, etc.	Eccentric rotating shaft generates a cycloidal movement that carries needles in the case. Transform member changes the transational movement to rotary.	Robust design with High Power, an integration of high load carrying reduction gear with a novel reduction system and an output bearing which can hold high load into one compact unit.
Teijin Seiki	Used in the joint of industrial robots.	-can achieve high torque with low power and high accuracy -high rigidity	Light weight, compact and highly durable.	Varied application beyondautomaticrobots. Eg. Used in ATC (Automatic Tool Changer),Welding positioner and other factory automation equipments etc.	The spur gear of the servo motor is rotated via input gear.Also in line with the gear ratio between the input gear and spur gear, the speed isreduced accordingly.	Precision Reduction Gear RV has been designed for being compact and lightweight while offering high precision and rigidity.
Sumitomo Fine Cyclo	Sumitomo'sE CYCLO can achieve higher performance in a smaller design envelope and thus lower costs.	Zero backlash, Minimal lost motion, High-torsional stiffness, high rigidity.	Smooth running spikeless gear, Smallest installation speed.	Airports Automotive Chemical Food and Beverage Forestry, Pulp and Paper Rubber Steel Sugar Textile Water Treatment.	The bearing of eccentric deforms the cycloid spline into an elliptical shape. The cycloid spline rotatesin counter clockwise direction,while the elastic deformation changes.	The Cyclo® speed reducer is characterized by the rolling action of its torque-transmitting components, the cycloidal discs. this unique design's rolling action results in high efficiency, quiet operation and shock load capacities of up to 500%.

Table 3. Comparison of High Precision Reduction Gears

In the Table 3, in order to reduce the backlash, Gear designs might be modified in various methods. Some techniques regulate the gears [Malakova 2022, Liang 2018] to a fixed teeth clearance all through initial assembly. With this approach, backlash ultimately will increase because of wear, which requires readjustment. Other designs use springs to keep meshing gears at a constant backlash level at some point of their service life. They are typically confined to mild load applications. Common design techniques consist of short input distance, spring-loaded split gears, plastic fillers, tapered gears, preloaded gear trains, and twin direction gear trains. For applications desiring zero or very low backlash, take into account special varieties of speed reducers that transmit motion with components apart from conventional gears.

7 CONCLUSIONS

With the improvement of science and innovation, particularly in the field of Automation, mechanical designers are care of gear manufacturing and improved technology. The necessities for the parameters of the precision of transmissions in the drives of hardware are expanding. The TwinSpin gears are classified as Hi-tech products and constitutes a novel arrangement, which incorporates radial axial bearing with a high precision gear into one condensed unit. Sumitomo offers remedy for every single application with its adaptable (Fine Cyclo) zero backlash precision gear drive units. While Teijin Seiki high load resistance with high reliable quality is accomplished by using the high-precision innovation in technology and fitting technique of the Precision Reduction Gear RVTM, which can be found in modern robots. The products are appropriate for applications, which require high reduction gear ratio, high kinematic precision, zero-backlash movement, high torque capacity, high rigidity, concise design in a constraint unit, speed just as low weight. During the analysis, in addition to the positive properties of the reducers, certain disadvantages associated with the complexity of solving the transfer of satellite motion to the centric one, the need for precise assembly with the observance of exact tolerances and the resulting possible losses, limited load capacity and service life were found. These aspects concern all three types of products. According to the available findings, the service life of the reducer is limited.

The basic technical parameters can be characterized according to the documents:

- transmitted power P = 0,07 ÷ 16,1 kW
- output torque T_2 = 37 ÷ 7500 Nm
- revolutions at the input n_1 = 150 ÷ 9 180 ot/min
- revolutions at the output n_2 = 8 ÷ 65 ot/min
- transmission ratio *i = 27 ÷ 179.*

The utilization of these necessities is exceptionally effective in the innovation and improvement of precision gear technology. The innovative production and positioning the automation and advanced robotics, are used in different machines and hardware. Principally, the term high-precision transmissions come from their producers, because of the precision that are endorsed by the manufacturers.

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