Overview of Robotic Reducer Testing Technology

Yuanchang Lin\(^1\), Wencheng Sun\(^2\)*, Guotian He\(^1\) and Zhenjun Zhang\(^1\)

\(^1\) Chongqing Institute of Green and Intelligent Technology, Chinese Academy of Sciences, Chongqing, China.
\(^2\) School of Intelligent Health, Chongqing College of Electronic Engineering, Chongqing, China.
Email: 814135955@qq.com

Abstract. As a high-performance precision reduction transmission equipment with large transmission ratio, high transmission efficiency, high transmission accuracy, stable transmission and low noise, reducer has been widely used in many fields such as industrial robots. The definition of the reducer is studied, the development history of the reducer is briefly introduced, and the classification and characteristics of the reducer are summarized, including traditional reducer, RV reducer, harmonic planetary reducer and cycloid reducer. A new generation of reducer and influencing factors such as transmission accuracy, transmission efficiency, backlash, torsional stiffness, noise, and assembly. The problem of precision reducer is analyzed, and finally the application and development trend of reducer are studied.

Keywords: Robots, reducers, inspection technology

1. Definition

The reducer is an independent component composed of gear transmission, worm transmission, and gear-worm transmission enclosed in a rigid shell. It is often used as a reduction transmission device between the original moving part and the working machine. It plays a role in matching the speed and transmitting torque between the prime mover and the working machine or the actuator. It is widely used in modern machinery.

2. Development History

2.1. Development History of RV Reducer

The RV [1] reducer technology originated from Germany. Dr. L. Braren (Lorenz Blanc) first proposed the use of cycloid tooth profile for precision mechanical transmission in 1926, and in 1931, he founded the "Segule" share in Munich, Germany. Co., Ltd., first started manufacturing and sales of cycloid reducers, and transferred to Sumitomo Heavy Machinery Industry Co., Ltd. of Japan in 1939 [2].

The concept of RV transmission was first proposed by Teijin Seikico., Ltd. in the early 1980s. According to the Cushman classification method, the transmission is a 2K-V planetary transmission [3]. In 2003, Teijin Seiki Co., Ltd. merged with Nabtesco Co., Ltd. to establish Nabtesco (Nabtesco), which has achieved rapid development and has now become a leader in the RV reducer industry.

After years of development, Sumitomo Corporation of Japan has become one of the largest companies in the world that manufacture cycloid reducers [4]. Nabtesco of Japan has been committed to the research and industrialization of RV reducers for a long time. It has mastered core technology
and is in an absolute leading position in the field of robot reducers. It has become the world's largest manufacturer of robot precision reducers.

In addition, other countries have also developed high-precision reducers similar to the working principle of RV reducers. For example, South Korea's SEJIN Company, on the basis of Japan's RV reducer, has developed a new cycloid tooth-shaped RV reducer (flat high-precision reducer) for industrial robots, and its products have formed multiple series [5]. The Dojen cycloid reducer produced in the United States is mainly used in the rotating arm drive device of the robot. It has high transmission accuracy. The reducer products of Spinea Company in Slovakia are widely used in industrial robots, CNC machine tools and other fields. It is the only product of its kind in the world.

The Li Lixing team of Dalian Jiaotong University who first carried out the research of RV reducer in my country has successively proposed the general formula of the cycloidal gear tooth profile [1], the cycloidal gear "reverse bow" tooth profile, tooth profile modification, dynamic transmission accuracy, etc. RV transmission optimization design theory, and successfully developed a prototype RV-250AII reducer for robots. Subsequently, the State Key Laboratory of Mechanical Transmission of Chongqing University, Tianjin University, Harbin Institute of Technology, Tianjin Vocational and Technical Normal University, Ningbo Zhongdali De Intelligent Transmission Co., Ltd., Qinchuan Machine Tool Factory and other units closely focused on the design theory of RV reducers, Relevant research work has been carried out in processing and assembly technology and performance testing, and many research results have been obtained [6-8].

At present, several companies including Shanghai Electromechanical, Qinchuan Machine Tool, Zhejiang Shuanghuan Transmission, Shandong Shuike, Nantong Zhenkang, Wuhan Jinghua, Han's Laser, Great Wheel Co., Ltd., Zhejiang Hengfengtai, Zhengshang Technology, Shaoneng Group, etc. are all vigorously Develop domestic reducer products [9].

Nantong Zhenkang Welding Electromechanical Co., Ltd. is the first domestic enterprise to realize mass production of RV reducers. Qinchuan Machine Tool & Tools Group Co., Ltd. has developed BX precision reducers, and the RV reducer of Great Wheel Co., Ltd. won the "Golden Ball for Domestic Robot Components". Award", Zhejiang Shuanghuan Transmission Machinery Co., Ltd. independently developed 14 models of SHPR series precision reducers for industrial robots. Wuhan Jinghua Reducer Manufacturing Co., Ltd. produces JHRV06, JHRV20, JHRV40 and other series of products. Zhejiang Hengfengtai Reducer Manufacturing Co., Ltd. has developed and produced 13 kinds of RV reducers. A breakthrough has been achieved. Ningbo Zhongdali De Intelligent Transmission Co., Ltd. has cooperated with scientific research institutes and universities to develop more than 9 kinds of products such as ZD-220BX-81-RVE cycloid pinwheel RV reducer. Shaoneng Co., Ltd. invested 2.6 RMB 100 million will be used for the industrial robot precision RV reducer project. Shanghai Lectra Precision Machinery Co., Ltd. has launched 4 series of precision reducer products, including LKRV-E, LKRV-C, LKRV-N, and LKRV-S. The RV series reducer developed by Shandong Shuike Machinery Manufacturing Co., Ltd., Haishang Group's innovative design concept, successfully developed the vector cycloid reducer independently, and its performance indicators have reached the international first-class level [10].

2.2. Harmonic Reducer Development History
The basic principle of harmonic drive was first proposed by American scholar C.W.Musser in 1955, which established the foundation for the development of harmonic reducer. In 1960, the first harmonic reducer met the world for the first time. At present, Japan Harmonic Drive Systems Inc. is the leader of global harmonic drive. Its harmonic drive products basically monopolize the main international market and control the market pricing power.

China introduced the first harmonic reducer in the early 1960s and began active research and development of harmonic drive products. In the second year, the domestic "harmonic reducer standard series products" passed the appraisal in Beijing. In 1993, my country formulated the harmonic reducer manufacturing standard GB/T14118-93, and became one of the countries mastering the technology of
harmonic gear transmission. At present, there are more than a dozen units in my country represented by Suzhou Green Harmonic Drive Technology Co., Ltd., Beijing Zhongji Kemei Harmonic Drive Company, Beijing Harmonic Drive Technology Research Institute, Beijing Precision Machinery Research Institute, and Zhengzhou Machinery Research Institute. Engaged in the research and production of harmonic drive products.

3. Classification and Characteristics
The reducer plays the role of matching the speed and transmitting torque between the prime mover and the working machine or the actuator. It is a relatively precise machine. The purpose of using it is to reduce the speed and increase the torque. It has a wide variety of different models, and different types have different uses.

There are many types of reducers. According to the transmission type, they can be divided into planetary gear reducers, gear reducers, and worm reducers; according to the number of transmission stages, they can be divided into single-stage and multi-stage reducers; according to the gear shape, they can be divided into cylindrical gear reducers, bevel gear reducer and conical-cylindrical gear reducer; according to the transmission layout, it can be divided into expandable reducer, split reducer and coaxial reducer; according to maturity, it can be divided into mature and mature.

Standardized products include: cylindrical gear reducer, worm gear reducer, planetary gear reducer, cycloid reducer and harmonic reducer, etc.; products that have been proposed and are being promoted include: three-ring reducer, movable tooth reducer. In recent years, patents have been proposed and applied for: filter reducer, shock reducer, rotary actuator, pure rolling reducer and equivalent elliptical harmonic reducer.

3.1. Features of Traditional Reducer
(1) The main feature of the worm gear reducer is that it has the opposite self-locking function.
(2) Compared with the size of the gear reducer, it can output larger torque.
(3) Harmonic gear reducer is a new type of reducer developed by the principle of planetary gear transmission.
(4) In order to achieve the purpose of reducing speed, increasing torque and matching inertia, most precision planetary reducers are installed on stepper motors and servo motors.
(5) Cycloidal pin gear reducer is a transmission model that adopts the principle of cycloidal pin tooth meshing planetary transmission. It has many advantages, has a wide range of uses, and can run forward and backward.
(6) The RV reducer is composed of a front stage of a planetary gear reducer and a rear stage of a cycloid reducer.

3.2. Features of the New Generation Reducer
3.2.1. Filter Gear Reducer. The rubber alloy filter reducer consists of an eccentric reduction mechanism, a filter spline mechanism, a filter gear and an output mechanism. Filter Gear Reducer consists of four main parts.

3.2.2. Vector Cycloid Reducer. The known cycloid reducer in the world mainly modifies the cycloid rather than the real cycloid motion trajectory. Haishang's vector cycloid reducer is a true cycloid motion trajectory, which has the advantages of zero backlash, full contact, and no dead ends.

Generally speaking, the robot reducer has high precision, high rigidity, high load rate, high speed ratio, high life, low inertia, low vibration, low noise, low temperature rise, beautiful appearance, light and small structure, convenient installation, precise positioning, etc. It is suitable for the acceleration and deceleration transmission of AC servo motors, DC servo motors, stepping motors, and hydraulic motors.
3.3 Influencing Factors

3.3.1. RV Reducer

(1) Factors affecting transmission accuracy

1) The tooth profile machining accuracy of the first-stage reducer mechanism has a small impact on the transmission accuracy, but the choice of the matching mode with the crankshaft and the planetary gear has a greater impact on the transmission accuracy [11].

2) The consistency of the eccentric phase angle of the crankshaft and the tooth profile phase angle of the cycloid gear.

3) The consistency of crankshaft eccentricity.

4) The position of the bearing hole of the cycloid has a great influence on the transmission accuracy.

5) The consistency of the two cycloidal wheels.

6) The consistency of the cumulative error of the cycloid.

7) The cumulative error of the tooth gap of the needle gear shell.

8) The coaxiality, position of the bearing hole of the planet carrier, and the coaxiality of the main shaft journal.

9) The matching selection between the tolerance of the planetary carrier circlip groove and the high tolerance of the crankshaft assembly.

10) The matching selection of crankshaft, needle bearing, cycloidal gear, and needle gear housing.

(2) Factors affecting transmission efficiency

1) By using a reasonable size chain to assemble the parts in place, reduce the friction loss inside the RV reducer.

2) Comprehensively choose a reasonable assembly method to reduce the starting torque of the RV reducer, that is, the input power of the input shaft, as small as possible while meeting the conditions of transmission accuracy, rigidity, backlash, and backlash.

(3) Factors affecting backlash, backlash, and torsional stiffness

1) The eccentricity of the crankshaft, the tooth thickness of the cycloid, the needle bearing, and the actual root circle of the needle gear housing determine the backlash, backlash, and torsional stiffness of the RV reducer.

2) The bearing rigidity of the main bearing and the assembly preload of the bearing determine the torsional rigidity of the RV reducer.

3) The backlash between the inner spline of the planetary gear and the outer spline of the input shaft, and the backlash between the planetary gear and the input shaft determines the backlash and backlash of the RV reducer.

4) The deviation of the center distance affects the size of the hysteresis.

5) The deviation of the modification amount affects the size of the backlash.

(4) Noise influencing factors

1) Tooth profile control of planetary gear and input shaft.

2) The accuracy of the whole machine assembly.

(5) Assembly accuracy

The assembly clearance of crankshaft, needle bearing, and cycloid determines the radial clearance of the RV reducer, and thus determines its comprehensive performance.

1) Optimize the assembly quality through group selection, interchange, and debugging, and improve the assembly accuracy and life of the product as much as possible.

2) Arrange assembly procedures scientifically and reasonably, and use special assembly tooling as much as possible to ensure assembly smoothness and consistency.

3) Optimize the assembly process as little as possible, reduce the assembly area, and increase the assembly rate per unit area.

4) The assembly is rigorous and meticulous to ensure the success rate of assembly, reduce unqualified products, and reduce assembly costs.
3.3.2. **Harmonic Reducer.** The transmission error source of the harmonic reducer can be divided into two parts, the error caused by the flexible wheel and the rigid wheel pair [12]; the error caused by the wave generator component.

In the flexible wheel and rigid wheel pair, there are the radial runout of the rigid wheel and the mounting hole, the matching clearance of the flexible wheel, the matching clearance of the output bearing, the radial runout and radial clearance of the output bearing, the matching clearance of the output bearing, etc. And so on will affect the transmission accuracy.

The wave generator is composed of cams and flexible bearings. Among them, the profile error of the cam, the matching clearance of the cam, the radial runout when the wave generator is installed, the radial runout and radial clearance of the flexible bearing, and the matching clearance of the flexible bearing all have an important influence on the transmission accuracy.

There is a problem with the precision reducer detector.

The problems of the precision reducer detector: poor structural rigidity, unstable accuracy, low detection efficiency, low intelligence and other shortcomings. The problems of online detection technology: low measurement accuracy, poor stability, high requirements for the measurement environment and measurement conditions, and poor applicability. Problems of the robot reducer: RV reducer has a special structure, and the force is complicated in the process of motion transmission. The research directions of existing domestic documents mainly include: research and development of new configurations, optimization of the structure of cycloids and other parts, and the transmission efficiency of the whole machine. Transmission accuracy and dynamic characteristics. Among them, the optimization of the part structure and the study of dynamic characteristics are mostly based on the analysis of individual parts, which will inevitably cause the optimization results to ignore the response of the parts when the whole machine is coordinated. The purpose of dynamic modal analysis is To prevent resonance caused by external excitation, even if the vibration characteristics of each part of the whole machine system are obtained, the natural frequency of the whole machine system may not be determined. Therefore, the modal analysis of only a single part is narrow. The difficulty of modal analysis of the whole machine is that the stiffness and damping of the system under a certain transient state need to be considered. For a long period of time, domestic researches on gear transmission systems have been linear theories, and have not considered non-linear factors such as gear clearance, meshing stiffness, and friction damping. We know that there is a certain gap between linear analysis and actual working conditions, so it is very necessary to consider the dynamics of the gear system under the non-linear framework. In addition, the RV reducer has high requirements for machining accuracy, and the method of using trial prototypes for test analysis is costly. With the development of computer virtual simulation technology and finite element analysis software, it provides an important means for further in-depth study of the dynamic characteristics of RV reducers.

Harmonic reducer, poor operation accuracy and accuracy retention; poor carrying capacity, easy to gear off under large loads, large transmission noise; backward production equipment, insufficient production technology, few product types; short product life, generally made in China. The service life of the harmonic reducer is about 5,000 to 10,000 hours, and the service life is greatly affected by the environment and temperature.

4. **Application and Development Trend**

RV reducers are widely used in industrial robots, machine tools, medical testing equipment, satellite receiving systems and other fields due to their small size, strong impact resistance, large torque, high positioning accuracy, low vibration, large reduction ratio and many other advantages. Compared with the harmonic drive commonly used in robots, it has much higher fatigue strength, stiffness and life, and the accuracy of the hysteresis is stable. Unlike the harmonic drive, the motion accuracy will be significantly reduced as the use time increases. Therefore, many countries in the world RV reducers are mostly used for high-precision robot transmission.

Harmonic gear reducer is a very versatile product, and its transmission advantages are very obvious. For a long time, harmonic gear reducer has been widely used in robot manufacturing, due to its simple
structure, precise transmission, and outstanding advantages of large-scale transmission ratio. Important fields such as medical equipment, radar equipment, optical manufacturing equipment, food processing machinery, papermaking machinery, and nuclear facilities. The manufacturing market has an increasing demand for harmonic reducers and requires higher quality. Many research organizations have always attached great importance to the research and development of harmonic reducers.

The development of reducer detection technology mainly focuses on four aspects. One is the online measurement technology during the processing of key parts of the reducer; the second is to optimize the structure design of the detector to improve the rigidity and versatility of the system; the third is to study error compensation theory to improve the detection accuracy of the system; the fourth is to study the new mechanism of the dynamic loading system to improve the stability of the test load.

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