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WAVE GEARS WITH INTERMEDIATE BODIES (state, results and problems)

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The results of practical application of wave gears with intermediate bodies have been shown. The reasons which interfere with their introduction in a batch production were analyzed. Priorities on these reasons elimination were set. The main directions of their solving were defined.

Gear drives find wide application in various branches of engineering beginning with low-power drives (from fractions of Wt) to high-power drives (hundreds of kWt and more) in mechanisms and devices of different purpose. Advantages and disadvantages of gear drives are described and analyzed in many papers. Nevertheless, searching and studying power transmissions which can provide the improved parameters of drive are still of great interest.

One of comparatively new power transmissions is a wave gear based on the principle of wave deformation of one of the links of thin-walled gear. A number of merits of the gear, first of all it is a high transmission ratio, has attracted the interest of designers in many branches of engineering first of all in aviation and space ones. First attempts to solve the problems connected with the development, production and operation of reducers on the basis of wave gears revealed the problems which were solved with large costs. Completely reversing loads on a thin-walled gear and cup of generator flexible bearing at general technology of their manufacturing resulted in breaking these details that is resource and reliability of transmission were low.

In Russia the development works of gears operative structures were carried out and are carried out now at different intensity [1–4]. The level of wave gear and reducer developments was brought to standard engineering computations and state standard разработок [4]. Due to the different reasons these works did not result in wave gear widespread adoption.

Rapid development of robotics in USA, Japan, South Korea and other countries required creation of the whole range of actuators including small-size drives with reducers. Creation of new technologies in material science, thermal treatment, metal treatment and wave gear calculation and development study allowed practically solving the problem of wave gear application in reducers of actuator drive in robotics. Wave gear made in Japan used in actuator drives of transfer line is presented in Fig. 1.

Simultaneously with wave gear studying the gears which would possess their merits but having higher resource and reliability are constantly searched for in the world. One of them is a wave gear with intermediate bodies. Its distinctive feature is replacing a thin-walled gearwheel by a compound wheel. The latter consists of the race in radial slots of which the intermediate bodies contacting with static spline teeth under the influence of generator are placed. Various details: plungers, injectors, coils of serpentine spring, bodies of rotation (balls and rolls) and other were used as intermediate bodies.

Works carried out in «SPC «Polyus», started in 1975 in Tomsk, in reducer creation for electromechanical actuators (EMA) of spacecraft navigation system showed the availability of applying wave gear with intermediate bodies in drives which must have high resource, high stiffness, minimal lost motion, low mass and dimensions. The carried out investigations and field experience in nonterrestrial objects composition showed that application of rolling elements and coils of serpentine springs as

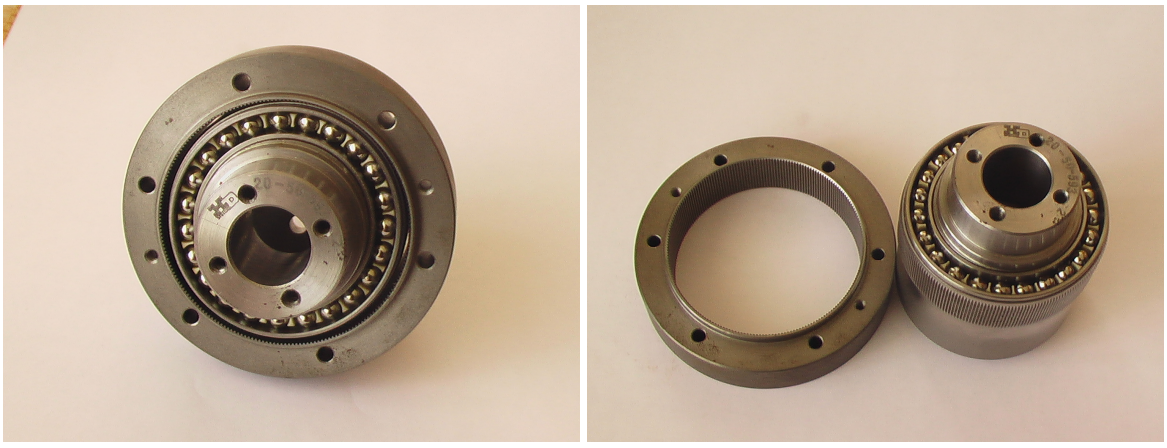

Fig. 1. *Wave gear with a flexible spline (on the left it is ready-fitted, on the right static spline is removed)*

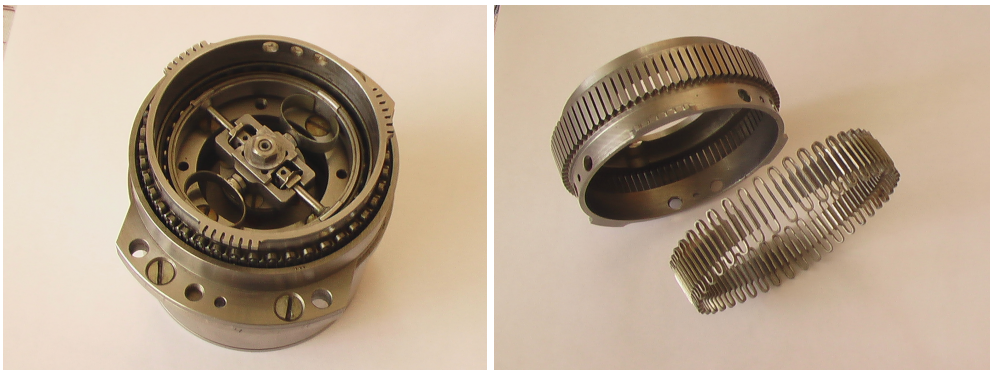

Fig. 2. *Wave gear with serpentine spring (on the left it is ready-fitted, on the right – serpentine spring and race with slots)*

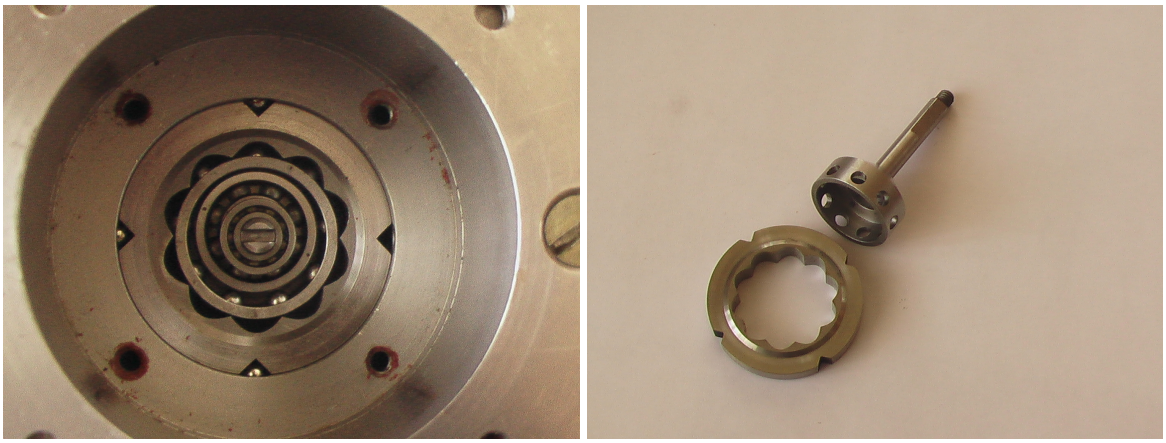

Fig. 3. *Wave gear with intermediate rolling bodies (on the left it is ready-fitted, on the right – static spline and race with slots)*

the intermediate bodies is the most perspective. A number of constructions of wave gears with these intermediate bodies were accepted as the inventions [5–10].

Calculation, construction and production of wave gear with intermediate body – serpentine spring did not cause special difficulties. For this purpose known methods of calculating wave gear and production technique of fine-module gears were applied and adapted [11].

The reducer of EMA drive in which the second stage is the wave gear with intermediate bodies – coils of serpentine spring situated in radial slots of the race is shown in Fig. 2.

In USSR the investigations of gears with intermediate rolling bodies including wave gears were carried out in Mogilev engineering institute, Kishinev polytechnic institute and Tomsk polytechnic institute. The first results of real work in Russia in wave gear production and introduction were published in papers [12, 13]. The work did not advance further than production of a single sample which turned out to be practically invalid. The reason is the lack of information in gears investigation.

The results of investigations in paper [11] allowed actually calculating, constructing, producing, studying and introducing wave gear with intermediate rolling bodies (WGIRB) into reducer composition of EMA drive (Fig. 3) which is still applied in «SPC «Polyus». A.E. Belyaev and E.B. Gindin – research workers of Tomsk polytechnic institute made a great contribution to these investigations.

Since the end of 80s of the last century and until now a number of organizations and companies in Tomsk: Manufacturing engineering RI; Tomsk transmission systems; Siberian Engineering Company and others develop drives on the bases of WGIRB.

Fig. 4. *Motor-reducer MR-270*

Fig. 5. *Drive of solar battery opening*

Fig. 6. *Motor-reducer MRT-2*

Fig. 7. *Motor-reducer of air heater drive*

A number of inventions of Siberian Engineering company [14] in which the WGIRB were used is presented in Fig. 4–9.

Fig. 8. *Stop valve drive*

Fig. 9. *Jack LEM-1,5-4*

Known foreign companies were interested in the results of investigations on WGIRB [11]. South Korean company «Daewoo» suggested developing the construction of a reducer entering into the composition of electric vehicle transmission. By the developed paperwork the reducer was made and tested at the model of electric vehicle. Japanese company «Komatsu» developing and manufacturing architectural and high-way engineering was also interested in these gears and supported their presentation in Japan. After that the contract was continued to exchange planetary gear unit for one of company articles to the reducer consisting of WGIRB. Paperwork has been carried out but the reducer was not made owing to the high cost of single procedures.

The main problems due to which these works were not carried out were: lack of reliable and approved design procedures, first of all, of stiffness and gear lost motion and manufacturing techniques of static spline gear ring including equipment and device for batch manufacturing (in perspective to tens of thousands of reducers of various standard size per year) with low cost.

Abroad the works on developing gears with intermediate rolling bodies are mainly carried out by American companies «Synkinetics Inc», «Advanced Energy Concepts 81», «Compudrive corporation». Single patents of Great Britain, Netherlands and Japan do not allow getting enough information about research situation in these countries.

The results of works on development and field experience of WGIRB in drives of various application show their incontestable advantages by a number of parameters in comparison with other gears. First of all it is high resource (more tan 10 years); minimal lost motion (2...3 ang. sec.); small dimensions and mass, but at the same time there is no their wide introduction. There several reasons for this: firstly, there is no theoretical studies allowing expanding fields of application of the given type of gear including CAD for simplifying laboriousness of design and construction of gears and reducers on their basis; secondly, it is labor-consuming and expensive engineering preparation of gear main details manufacturing especially of static spline. For today only two techniques of static spline gear ring manufacturing are known: the technique of tooth profile exchange by broken curve, composed of arcs with constant radii [15] and the technique of tooth profile cutting by electrical-discharge machines [16]. Both techniques are laborious and do not support the quality of tooth working surface.

At instrument engineering department of TPU in Tomsk the WGIRB integrated study group is formed for solving the problems of their introduction into drives of various application. The integrated study means the reducer development starting with the design and until accessible manufacturing technique of main elements, first of all, static spline ring gear.

Actually, now only those techniques are known according to which it is possible to calculate the geometry of static spline tooth profile and to carry out force design that imposes constraints on application of these gears. It is necessary to carry out theoretical studies and develop on their basis engineering design procedures of stiffness, lost motion, relative slip velocities of gear main links, dynamics and others. Constructions of gears with adaptive generators supporting intimate contact also require additional research of geometric and force design. For conforming to the modern level of development the CAD system requirement which would include: mathematical simulating, calculation part and construction paperwork outlet appears.

Creation of special equipment and devices allowing supporting high quality of static spline ring gear with minimal costs is meant by accessible engineering that is a great independent engineering problem. High laboriousness (tens of hours) of known manufacturing techniques of ring gear is determined by low capacity of metal cutting operation at coordinate and electrical-discharge machine. High prices of this equipment and skilled attendant requirements increase significantly the cost for components manufacturing. These reasons restrain WGIRB introduction into batch manufacturing. It is possible to solve the problem due to the usage of special equipment and instruments supporting high capacity and low cost of procedure of static spline ring gear treatment. Special equipment should be created on the basis of batch-produced universal metal-cutting machines by means of their modernization. Such approach allows decreasing laboriousness owing to use of metal-cutting productive operations (milling and polishing) and procedure cost (rather low expenses for equipment, instruments and semiskilled attendant).

Conclusion

Abstract of development results and maintenance of reducers on the basis of WGIRB in structure of drives of various assignment gives the opportunity to state the following main conclusions and set problems for realizing broader application of the given type gear:

- Wave gear with intermediate rolling bodies are the perspective type of transmission possessing merits of wave gear and having a set of advantages supporting high resource, lost motion, stiffness values and oters;
- Primary tasks of WGIRB integrated study group are carrying out additional theoretical studies and their development to engineering design procedures including CAD as well as the development and production of processing equipment and instrument for manufacturing details with working surface high quality and supporting high capacity with low cost.

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PRECISE REDUCER OF INCREASED DURABILITY

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The results of works on creation of precise reducer being a part of spacecrafts have been presented. Modular composition of reducer construction on the basis of wave gear with intermediate rolling bodies was described. Reducer construction with modular composition of kinematic circuit was offered. In this circuit the gears with adaptive generators supporting elastic tightness in interlock were applied.

High demands of space technology determine the parameters of all blocks and components being a part of spacecraft. The main parameter for the spacecraft is a high resource. One of the blocks defining spacecraft working capacity is navigation system which includes also electromechanical actuators. In some of them the rotation drives of cardan suspension frame (RDF) are applied. The progressive trend in RDF drives creation is electromechanical reduction drive.

Presence of reducer in drive composition allows obtaining certain advantages but imposes high requirements to its parameters.

Works on RDF reducer creation were started since 1975 at «SPC «Polyus» in Tomsk [1]. The first attempts to solve the problem using known gear constructions did not achieve positive result. The most difficult task was to eliminate gaps in reducer kinematic circuit that as one of the main requirements. Lost motion of output shaft should not exceed 2 ang. sec. per the whole resource which is more than 10 years. As a result of carried out researches including theoretical ones from creation of new constructions, development of parameters design procedures to the development of production and control techniques of reducers elements and experimental