DESIGN AND PRODUCTION TECHNOLOGY OF SPECIAL FRICTION CLUTCH INSIDE INNOVATIVE REDUCERS OF RAILROAD SWITCHES

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Abstract

The article discusses the development of innovative technologies aimed at increasing the speed, efficiency, productivity and safety of railway transport systems based on ensuring modern requirements for dimensions, the number of components and the reliability of manufactured switch devices. The design of a special three-disk friction clutch is designed, which is placed between the gears of a double-crown gear block of the second stage of a package innovative reducer intended for mechanical transmission systems of railroad switch devices, based on their design and functional features. The design of the friction clutch is quite compact, provides for a decrease in the dimensions and weight of the entire transmission mechanism, an increase in its reliability and technical indicators, and protection of the system from overloads. Considering the advantages and technical level of the reducer kit, with a specially designed friction clutch, it is recommended for use on switch drives of the "СП" brand in the railway transport systems of the CIS countries.

Keywords: Railroad, switch drive, innovative, package reducer, friction clutch, construction, technology.

I. Introduction

Thanks to the new opportunities presented by the last industrial revolution, enterprises are striving to improve the quality of their products as much as possible to gain a competitive edge in the market. Over time, the goal of human industry has been to make each product more ergonomic, aesthetic, efficient, productive, and reliable. Accordingly, the size of the products should be smaller, the number of components as minimal and reliable as possible, and the mechanical systems used are continuously improved. Various research is being conducted to create more modern, compact, and safe transmission mechanisms [1-4].

In the modern era, one of the fields directed towards the application of continuously developing and more advanced technologies, particularly due to the importance of speed and safety, is the railway transportation system [5]. It also plays a significant role in the political activities of countries worldwide. The transit corridors and logistics of this system constantly contribute to the economic relationships between countries. Ensuring the safety, productivity, and sustainable development of railway systems, which transport passengers and large volumes of cargo over long distances efficiently, is always a priority. To ensure the proper functioning of railway infrastructure, the coordination and safety issues between its various mechanisms are of special importance and must be efficiently resolved.

The railway system's structures and equipment are continually adapted to meet the modern structural and technological requirements, thus improving the overall performance of the system. One of the directions for increasing the productivity of the railway system is the railway switch, which plays a crucial role in regulating the routes of the rolling stock (trains, locomotives, wagons, etc.). In the railways of Azerbaijan and other CIS countries, the main switches used to facilitate the transition of rolling stock from one track to another are primarily of the "СП" brand (refer to Figure 1, Figure 2). The speed and reliability of the switch operation depend on the mechanical transmission mechanism, particularly the working condition of the protective friction clutch, which is a key element of the latter [6]. Therefore, the rational design of the friction clutch in the double-crown gear block of the package reducer and the development of its manufacturing technology is a pressing issue.

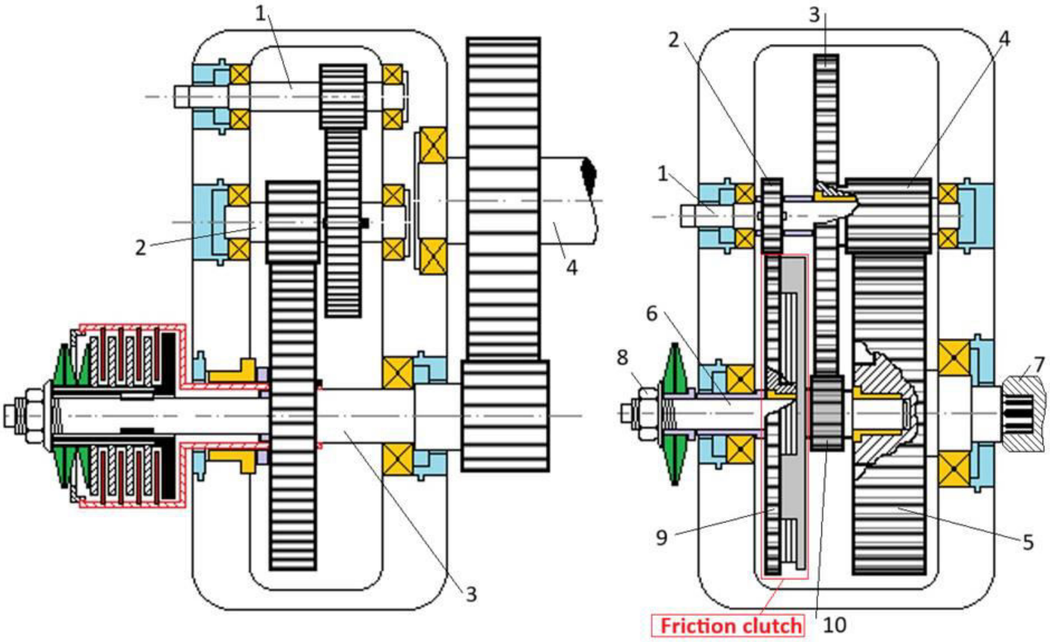

Figure 1: a) *Existing reducer of the "СП" brand railroad switch; b) Protective clutch designed inside of package brand reducer*

II. Statement of the problem

The increasing speed and safety requirements in railway transport, as well as the identification of the shortcomings of the components constituting the system, and the need for their elimination to ensure more reliable operation and productivity, are critical issues. Therefore, the functionality and reliability of "СП" brand switches have been investigated, and it has been determined that the reliability of the mechanical transmission system, consisting of a two-stage reducer and an open gear stage, is lower due to open gear drive stage [7, 8]. In order to make the gear transmission mechanism fully enclosed, an innovative mechanical transmission for the railway switch has been developed by replacing the existing reducer and open gear transmission with a compact three-stage package reducer [9]. The proposal of a three-stage package reducer instead of the existing reducer and open gear transmission for the railway switch has ensured the improvement of the technical level indicators of the transmission and compliance of the mechanical system with modern requirements [10]. The package reducer, which differs from traditional reducers in its structural and functional characteristics and has its main components consisting of double-crown gear blocks, is an interesting issue in terms of ensuring the compactness and reliability of the protective clutch designed inside the mechanism. Its positive solution is an essential part of the efficient operation of the switch. Therefore, when designing the clutch for the package reducer, the features of modern designs and technologies compatible with this field are utilized [11, 12]. It is clear that the role of the protective clutch is to prevent the overload of the motor by preventing foreign objects (such as stones, iron pieces, etc.) from falling between the switch blade and the rail, which would otherwise cause the transmission motor to fail.

Taking into account the above-mentioned factors and the operating conditions of the clutches, the need arises to develop the construction of an optimal compact protective clutch in the double-crown gear transmissions of the proposed innovative transmission for "СП" brand switches, as well as the manufacturing technologies of its components.

It should be noted that some of the reducers marked with "СП" (for example, "СП-2", "СП-8", "СП-10") are lubricated with solid grease on the friction discs, while others (such as "СП-6", "СП-6М", "СП-6МГ") are lubricated with liquid oil inside the reducer [6, 13, 14].

The aim of the work is to rationally place the friction clutch in the reducer designed for the railroad switches, design its construction, and develop advanced processing technologies for its components.

III. Methodology

To achieve the set goal, the following constructive and technological issues must be addressed:

Constructive Issue: Ensuring the minimum number of parts, along with the friction clutch, while determining the dimensional measurements of the gearbox and ensuring its reliability.

Technological Issue: Developing advanced methods for the machining, assembly, and repair technologies of the friction clutch components.

The existing transmission mechanism of the "СП" brand switch used in the railway system of the CIS consists of three stages and four shafts (1-4) (refer to Fig. 1, a). Since sufficient information is provided in the literature regarding the mechanical transmission mechanism of the "СП" brand switches and the features of the package-type reducers, these issues are not discussed in detail in this work [6, 10].

To ensure the high operational performance of the protective clutch, the following provisions and requirements are considered when designing it within the package type reducer:

1. Minimum mass and dimensional measurements: If the friction clutch is placed inside the reducer housing, no additional housing is required;
2. Minimal number of components: The number of key connections and friction discs in the clutch must be minimized.;
3. Simplicity of maintenance and repair: The lubrication of the friction discs should be performed together with the lubrication of the reducer's gear, and the replacement of the friction discs should be simplified by the ease of disassembling and assembling the reducer;
4. Ease of adjustment: The nut for adjusting the friction disc compression force must be located in a convenient place;
5. The manufacturability of the manufacturing and assembly of the clutch parts must be ensured..

Taking into account the set requirements, existing conditions, and given data (such as the dimensions of the reducer, kinematic and structural configuration, the position within the switch box, internal space of the box, etc.), an analysis of the system was carried out. It was determined that since the driving shaft (1) of the first stage is connected to the motor shaft, it is not possible to install the friction clutch between the driving gear (2) and the driving shaft. In the last (III) stage, i.e., between the gear wheels (3-4) of the second two-crown block or between the driven gear (5) and the driven shaft (6), the design of the friction clutch also appears inefficient, because (refer to Figure 1, b):

1. This stage is heavily loaded, and since the transmitted torque is large, the number of friction discs must be increased or their diameters must be larger.;

2. The electric-automation device installed in the output direction of the reducer and the main shaft of the transmission (7) make it impossible to place the adjustment nut (8) (refer to Figure 1, b).

Therefore, it is possible and efficient to design the protective friction clutch between the gear wheels (9, 10) of the two-crown block, which is mounted on the driven shaft, i.e., between the driven gear of the first stage and the driving gear of the second stage (refer to Figure 1, b).

Since the working parts of the clutch are placed between the driven gear (8) and the driving gear (9), each of which also serves as a half-clutch, its dimensions must be coordinated with the dimensions of the gear wheels.

The half-clutch are part of the driven gear (8) and the driving gear (9) and are in static contact only with the discs. Based on the operational experience of friction clutches, materials such as hardened steel or metal-ceramics are chosen for the friction disks.

Since the gear wheels of the block separately perform the function of half-clutch, the dimensions of the friction discs must also be coordinated with the sizes of these gear wheels. Therefore, the friction discs are accepted to have the largest possible areas, and their number is determined functionally through calculation. The clutch is designed for "СП" brand railway switches. Thus, the outer and inner diameters of the compressing discs are determined based on the dimensions of the driven gear of the stepped gear. As a result of the calculation for the package reducer designed for "СП" brand railway switches, the dimensions for the driven gear are as follows: Pitch circle diameter: $d_2 = 150\ mm$; Outside circle diameter: $d_{a2} = 154\ mm$; Root circle diameter: $d_{f2} = 145\ mm$; Gear width: $b_2 = 5\ mm$; Gear hub diameter: $d_{t2} \approx 34\ mm$; Gear hub length: $l_{t2} \approx 12\ mm$.

The two pressing discs of the friction clutch (with thickness initially accepted as b_S=1,5 mm, and later verified through calculation) are mounted on the hub of the driven gear (9), which also serves as a half-clutch, and rotate together with it. Therefore, the outer surface of the hub and the inner surface of the discs are designed as cylindrical surfaces cut by symmetrical sectors. Thus, the outer diameters of the pressing discs are taken as D_{Sx}=133 mm, and the inner diameters as d_{Sd}=34,5 mm (refer to Figure 2, a-b).

Between the pressing discs, a driven disc (initially accepted with a thickness of b_A=3 mm) is placed, which has three key projections on its external cylindrical surface. This disc, with its key projections-teeth, is inserted into the three keyseat grooves of the driving gear's (10) cylindrical structural element (referred to as the cover here), and is mounted on its internal cylindrical surface. The outer and inner diameters of the driven disc are D_{Ax}=134 mm and d_{Ad}= 67 mm, respectively; the height of the teeth and the length along the circumference are h_t=3,5 mm and L=8 mm (refer to Figure 2, b).

The outer and encompassing inner diameters of the cover, the height, length, and depth of the tooth grooves, the thickness of the cover, and the depth of its encompassing inner surface, as well as the diameter of the cover's hub and the diameter and depth of the groove into which the hub of the driven gear of the first gear stage can fit during the compression of the discs, are determined based on the intended function and operating conditions. These values are calculated using known formulas according to the methodologies for determining the structural elements of machine components. The remaining dimensions are taken as design choices (refer to Figure 2, a-b; in the figure, only nominal dimensions are provided, surface qualities, etc., are not specified) [8, 15].

The design of the friction clutch for the "СП" brand railway switches was carried out using the well-known methodologies provided in the literature, based on the operating conditions and parameters [16, 17].

The force exerted by the pressing discs: F_a= 8289,6 N;
The number of friction surface pairs in the clutch:

$$i = \frac{K \cdot T}{f \cdot F_a \cdot R_{or}} = \frac{1{,}3 \cdot 14{,}06 \cdot 10^3}{0{,}06 \cdot 8289{,}6 \cdot 50} = \frac{18278}{24868{,}8} = 0{,}73 \approx 2 \qquad (1)$$

Where: K=1,3 – operating mode coefficient;
T=14,06 Nm; - the maximum transmitted torque of the clutch,
$F_a = 8289{,}6\ N$ – the force exerted on the pressing discs;
$R_{or} = 50\ mm$ - the average radius of the friction surface pairs;
f = 0,06 – the friction coefficient between the treated steel surface.
The projections-teeth of the driven disc in the clutch have been checked for crushing stress:
$\sigma_c = 14{,}1\ N/mm^2 < [\sigma_c]$=(25÷ 35) MPa (condition is met)

To facilitate the repair process and ensure the longevity of the main parts, the number of friction pairs is assumed to be 2 (refer to Eq. 1) and the working surfaces of the friction discs are assumed to be the friction surfaces. The dimensions of the nut, which will compress the half-clutches by being connected to the intermediate shaft, have been selected according to the existing "СП" reducer's clutch. Additionally, the threads have been checked for shear stress.

The designs of the friction clutch parts are presented in a simplified form (refer to Figure 2, Figure 3).

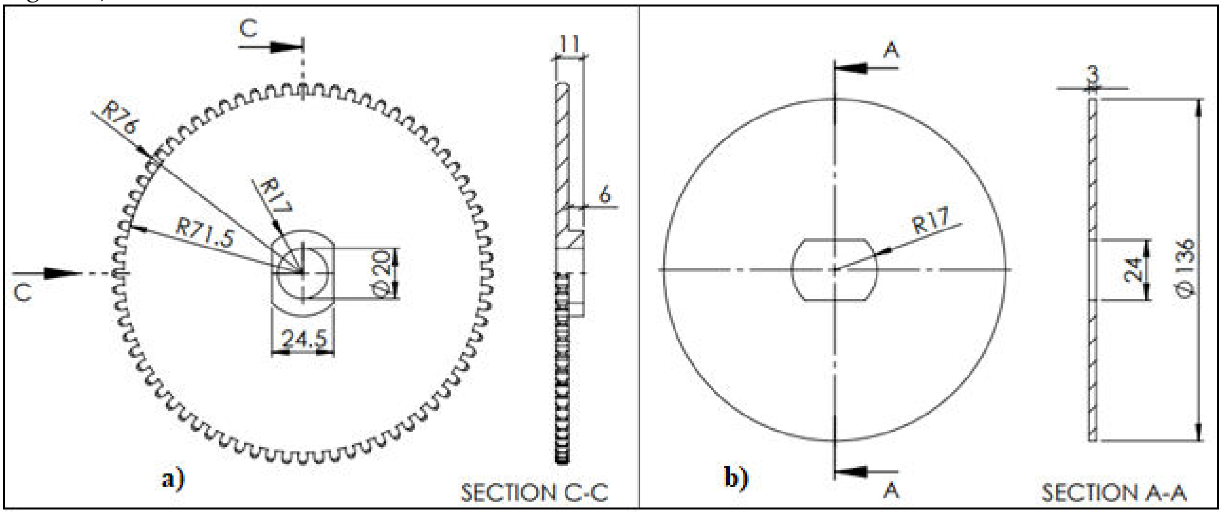

Figure 2: *Left half-clutch: a) driven gear of the first stage;*
b) pressure discs of the friction clutch

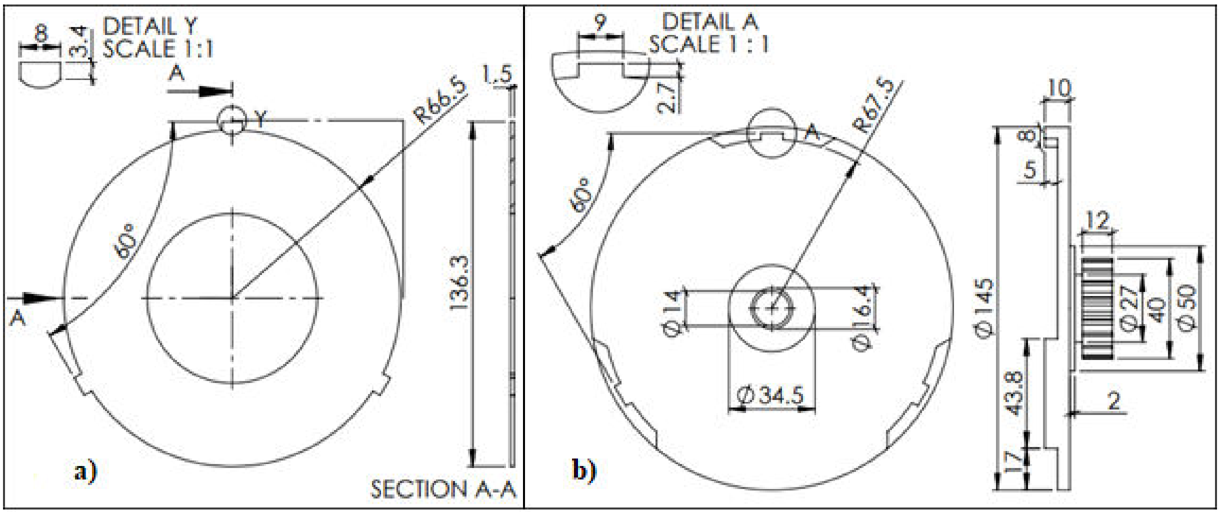

Figure 3: *Right half-clutch: a) driven disc of the friction clutch; b) drive gear of the second stage*

Manufacturing technologies of the friction clutch components. When developing technological processes for the components of the clutch, typical technologies for the components have been used [18, 19]. However, in this case, the structural features of the half-clutchs and discs, as well as the issues related to their base processing during machining, are new and different. Therefore, the creation of advanced technologies is required.

The main components of the clutch, which are different from traditional designs, consist of 5 working parts: three friction discs and two half-clutch gear wheels. Their manufacturing is carried out using two groups of technologies: for the gear wheels-half- clutchs and friction discs:

Manufacturing of half- clutch gear wheels**:**

Mass Production: 1) Turning of the rotation surfaces according to the typical gear wheel technology, 2) Rough polishing of high-precision rotation surfaces, 3) Milling of flat surfaces on the hub using a milling machine, 4) Gear cutting, 5) Thermal processing, 6) Cleaning, 7) Fine polishing;

Individual, small-scale production: 1) Turning of rotation surfaces in two placements on RPI machines, milling flat surfaces on the hub in sequence; 2) Rough polishing of high-precision rotation surfaces; 3) Gear cutting; 4) Thermal processing; 5) Cleaning; 6) Fine polishing.

Manufacturing of discs**:**

In mass production for steel discs: 1) Stamping along the contour from sheet material; 2) Thermal treatment; 3) Cleaning;

For steel discs, individual, small series production: 1) Cutting along the contour from sheet material using laser (or water jet); 2) Cleaning; 3) Thermal treatment; 4) Cleaning.

For metal-ceramic discs: 1) Selection and mixing of materials (metal parts: stainless steel and alloyed steels; ceramic parts: aluminum oxide and silicon carbide); 2) Addition of binder materials to obtain a homogeneous mixture; 3) Pressing the mixture into a disk shape; 4) Heat treatment (sintering at 900-1400°C) to achieve a hard crystal structure; 5) Surface treatment - applying coatings (titanium nitride or boron nitride) to the working surface of the disk.

IV. Discussion

The driven gear of the fist stage moves together with the shaft. Since the gear also serves as a half-clutch, its hub is designed according to the width of the driven discs, with the shape and dimensions shown in Figure 2. The dimensions of the clutch components have been determined using known calculation methodologies and are provided in the figures [16, 17]. The internal cavity of the two pressing discs, which are rigidly mounted on the hub of the gear, is designed in the form of a profile joint to match the hub of the gear, ensuring its movement together with the gear.

Between the pressing discs, in case of excessive loading, a driven disc is placed, which can move freely, independent of the driven gear and the pressing discs. This disc has three protruding teeth positioned at a 120° angle relative to each other on its outer circumference. Its internal diameter is taken as 0,5037 times the external diameter of the friction surface, in accordance with the allowable limit (refer to Figure 3).

To drive the intermediate stage's driving gear by meshing with the teeth of the compressed driven gear, a cylindrical cap is designed with corresponding holding cavities for the teeth, serving as a second crown for the gear, with dimensions matching those of the teeth (refer to Figure 3).

Since the gears are tightened with a nut, there is no need for a key connection. Within the specified limit, the driving moment is transmitted, and the gears rotate together with the shaft.

V. Conclusions

1. A protective friction clutch has been designed within the proposed three-stage, two-shaft package-type reducer, which serves as the mechanical transmission mechanism of the railway switch. The clutch is installed between the gear wheels of the intermediate stage's two-crown gear block, ensuring the minimization of component count, along with the dimensions of the reducer, and guaranteeing its reliability together with the friction clutch.

2. Based on the functional design parameters and the structural features of the two-crown gear blocks, the main functional components of the mechanical system were calculated, and their constructive dimensions were determined. The working drawings have been developed accordingly.

3. Taking into account the types of production, progressive technologies are proposed for the manufacturing of the main working components of the friction clutch.

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