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Safety of mining machinery drives – selected issues

The machines used in contemporary mining work under extremely demanding environmental and working conditions, especially when variable loads occur during the mining and transport. This causes a dynamic load occurrence, particularly influencing the mechanical subunits of the machine drive system; the dynamic loads negatively affect the durability, reliability, and security of its use. Counteracting the negative results of the mutual dynamic interactions between the parts of the machine drive is helped by the application of appropriate methods and measures leading to diminished transferred dynamic loads. The specifics of the working conditions in mining machines causes high dynamic loads during electrical or mechanical starting. We present models of torsionally flexible couplings applied in mining machines having a reduction of the dynamic loads occurring during stabile work as a target.

Key words: *protection, overload, drive system*

1. INTRODUCTION

Basic mining machines working in underground coal mines are excavating machines that convey waste from the longwall. The nature of these machines makes them some of the most-exposed machines in the mining industry. This situation requires special attention to the process of their design and operation.

The basic mechanical unit that mediates the performance of each mining machine is the propulsion system. Its components usually include such elements as an electric motor, gears, couplings, and components or actuators in the form of a mining body (drill) or drum.

The main mechanical assemblies in the drive system of excavating and transporting machines (such as the couplings and gears) are subjected to particularly intensive variable-load operating forces with significant instantaneous high-frequency overloads that occur primarily in unsteady starters (scraper conveyors) as well as during fixed work. The ultimate effect of these adverse effects is reducing their reliability and durability. A remedy for such adverse operating conditions is to use special technical measures to protect the components of the drive system from overload. An example of this may be the drive system of a floor conveyor, where significant problems are associated with its start up. One way is to use a starter device to facilitate this process by electrical and/or mechanical means. As mentioned above, the overloads also occur during the operation of the fixed machine. In this case, torsionally flexible couplings of different designs are used.

In this article, an overview of the protection of the propulsion systems of selected mining machines is presented in a comprehensive and synthetic manner. The main focus is on a mechanical solution used in mining machine drive systems.

2. PROTECTION OF DRIVE SYSTEM OF EXCAVATING MACHINES

In the process of extracting hard coal, roadheaders and longwall shearers are used as mining machines for the excavation of waste.

Roadheaders are used for drilling the corridors that provide access to coal, salt, and copper ores. The individual working motions of the actuators are realized by means of drive mechanisms of the excavating body, crawler chassis, and excavator loader.

The most-heavily-loaded is the propulsion system of the working heads. Admittedly, their start-up is usually without load, but there are high dynamic loads from the cutting of coal or stone by the knives. The instability of the mechanical parameters of the workmanship and method of moving the workpiece heads are the reason for the variable load in the drive system from the electric motor to the working heads. Figure 1 shows an example of the construction of an AM-50z roadheader. Depending on the design of the mining machine, the reducer can take a different form in kinematic terms, but the coupler between the input shaft of the reducer and the motor is always a flexible coupler. In most cases, it is an insert coupling or, as in the case of the AM-50z roadheader, a finger coupling.

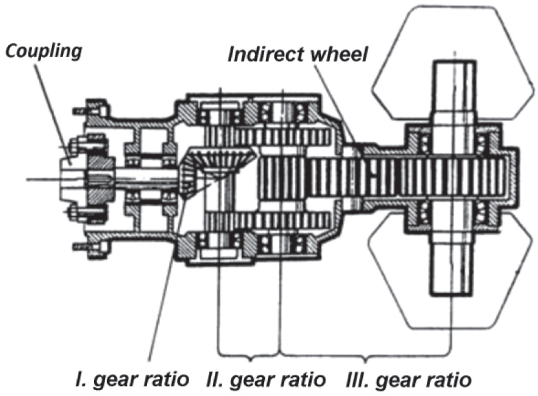

Fig. 1. Drive system of head of AM-50z roadheader [1]

This clutch is designed to alleviate the dynamic load on the transmission input shaft from the engine at start-up and then relieve the load on the motor shaft from the response to the cutting load. Figure 2 shows the passive member of the insert coupling, and in Figure 3, the finger clutch of the longitudinal milling head is shown.

Fig. 2. View of passive member of insert clutch used in roadheader

Fig. 3. View of passive member of finger clutch used in roadheader

In addition to the flexible coupling, friction clutches can also be used (as in the case of the AM-75 combine). It also functions as an overload clutch.

The overload protection in the shaping body is predominantly handled by the expansion ring (Fig. 4), by means of which the torque is transferred from the passive shaft of the reducer to the cutting head.

It is a combination of a cylindrical smooth hub of the cutting head with a cylindrical smooth output shaft [2]. When an overload occurs, the friction force in the ring is exceeded, and there is a slip and a break in the torque transmission.

Fig. 4. View of expansion ring for use in head of mining roadheader

In addition to the direct methods of securing the propulsion system of the digging machine in the roadheader against overload, indirect methods are used, which include [2]:

- thermal protection of the drive motor,
- limiting the clamping force of the cutting head as the pressure in the power supply of the boom tilting cylinders increases,
- limiting the speed of moving the cutting head as the power consumption of the engine in the cutting system increases.

Another machine used for the simultaneous excavation and loading of waste on the conveyor is a shearer. It forms part of the longwall complex. Figure 5 shows an exemplary view of a geometrical model of the drive system of the mining body.

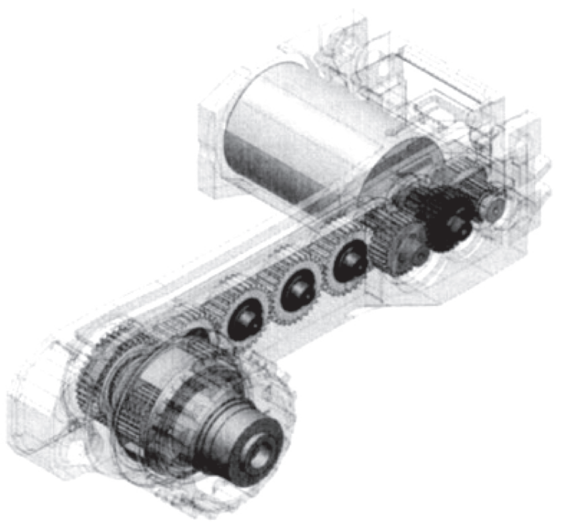

Fig. 5. Geometrical model of longwall shearer drive system [3]

The overload protection of the driveline can be achieved by direct and indirect drives. Indirect methods include all of the controls included in the harvester control system, such as the Joy's company Faceboss control system, where the engine parameters are controlled without blocking or overheating.

The highest load from coal mining is in the propulsion system of the mining body. It is true that the start-up process itself is not a problem (as it takes place without a load), but during the cutting process, there is a high degree of variability over time, and its intensity depends on the speed of the combine.

Protective gear assemblies for the drilling unit and overload drive may be fuse shafts that transmit the engine torque to the first gear stage [4, 5]. This solution is used in the KSW 460, KSW 620E, and KSW-1140E mining combines, for example. The fuse shaft has an undercut, and in the event of an overload in the drive system, it is destroyed there. This shaft is easily replaced by a new one.

3. PROTECTION OF DRIVE SYSTEM OF TRANSPORTING MACHINES

3.1. Scraper conveyors

Scraper conveyors are the beginning of the conveyor belt from the longwall. The operating conditions of the wall conveyor make them some of the heaviest operating conditions in underground mining. Considerable problems are caused by the start-up, mainly due to the mass of the excavated material on the route as well as too much initial tension on the chain and any problems on the supply side of the engine (the status of the mine network, incorrect drive order, etc.).

In addition to the difficult start-up, the main mechanisms of the drive system of the floor conveyor are exposed to particularly intensive operating loads in the form of variable loads with significant instantaneous overloads (also during steady-state operation).

Counteracting the unfavorable effects of the interference of the elements of the floor conveyor drive systems is possible through the use of appropriate methods and measures leading to the reduction of dynamic load transmission, as they have a significant impact on the development of degradation processes (especially fatigue).

As mentioned earlier, a big problem is the start-up of a loaded conveyor. This is particularly important because mine practice shows that the wall conveyor is switched on and off relatively frequently [6].

It is possible to start up the loaded conveyor by taking the appropriate technical measures. It can be carried out by electrical (the simplest solution is to use a two-speed motor) or mechanical means. The electric starter methods/devices are:

- contactor starters,
- thyristor units,
- frequency converters.

Enabling the start of the conveyor as well as limiting the negative effects of the interaction of the propulsion system components during the fixed operation is also possible through the use of simple torsionally flexible couplings and moreadvanced overload / start couplings construction.

At present time, in the mining scraper conveyors between the motor and gearbox, flexible couplings with elastomer or polyurethane inserts (Fig. 6) or two-component (Fig. 7) are often used.

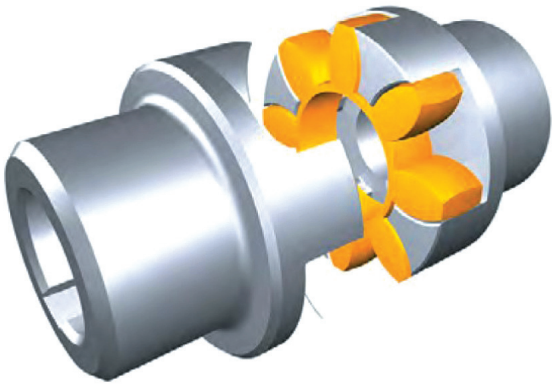

Fig. 6. One insert flexible coupling SP (ASR) [7, 8]

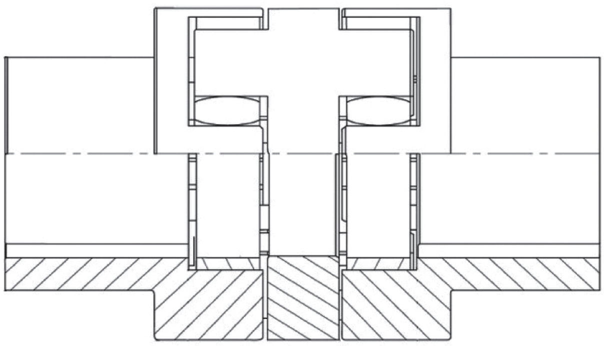

Fig. 7. Two insert flexible coupling SPP (ASR) [7]

In the floor conveyors, a connection of the flexible and overload couplings is also used. Figure 8 shows an example design of such a solution.

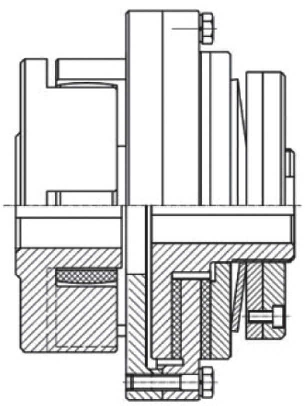

Fig. 8. Overload coupling APMX [8]

This is a typical insertion clutch with an adjustable torque value at which friction on the friction pads occurs and disconnects the drive.

Other couplings are also available. An example is the clutch, which is manufactured by RFM RYFAMA (Fig. 9), where the flexible element is a rubber torus in which the steel sleeves are vulcanized. In the bushes, there are alternating steel bolts attached to the discs located on the active and passive couplings [9].

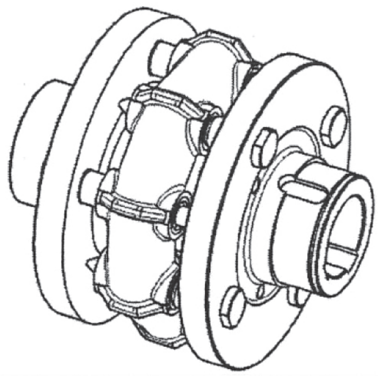

Fig. 9. Flexible coupling of RFM RYFAMA [9]

In turn, the original solution of the flexible coupler with removable elastic part (insert) without dismantling the engine is offered in the TZ Polska company. These are the BHDD and SDD clutch couplings. They differ mainly in the construction of the replacement part, more specifically in the shape of the fuselage and elastic insert. An example of such a solution is shown in Figure 10.

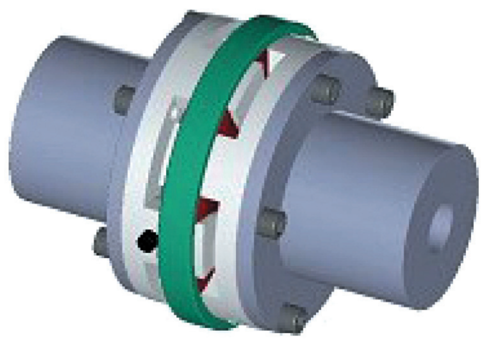

Fig. 10. Tschan BHDD-type coupling [10]

In conclusion, insert couplings are used in the drive systems of floor conveyors due to their low cost of production, durability, and lack of service during operation. They suppress the torsional vibrations; however, they have a relatively small relative angle of the twisting of the members and do not sufficiently support the start-up process of the conveyor.

Tire couplings (Fig. 11) may also be used. They carry large torque and have a significantly higher susceptibility to the elastic than the inserts. Their additional advantage is the possibility of replacing the elastic pad without dismantling any of the components of the drive system.

Fig. 11. Tire coupling [8]

A new type of clutch, which can find use in mining machinery drives in the near future, is the Dodge Raptor clutch. It combines the advantages of the high elasticity of a tire clutch and the easy replacement of the elastic cartridge with high durability and reliability. Figure 12 shows the Raptor clutch with fuses.

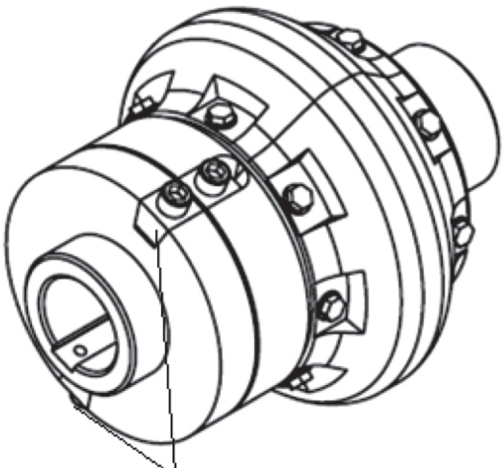

Fig. 12. Raptor-SK clutch with fuses [8]

The use of fuses in the coupling reduces the value of the transmitted torque to a value beyond which the chopping occurs; consequently, the drive will be disengaged.

The Raptor clutch coupling element consists of two parts. It is made of natural rubber and has a special design for high strength in sensitive areas. The toughness of this type of coupling is several dozen degrees higher than other clutches.

As mentioned earlier, elastic couplings have a number of drawbacks. First of all, they do not fully protect the components of the drive system from overload and do not meet expectations during the so-called heavy start-up, which can lead to the inability to start the conveyor without first unloading it. Therefore, hydrodynamic couplings have been widely used in the Polish mining industry.

Hydrodynamic couplings are a complex system in which the transfer of torque from the active member – the pump impeller to the passive member – is called a turbine impeller by means of a liquid connector [11–12]. There are mainly fixed couplings with or without retarder and flow [9].

For conveyors where heavy start-up is expected, the use of fixed-displacement torque couplings with a retard chamber is particularly applicable. The task of the extra chambers is to collect a portion of the fluid from the working chamber so that it is less dense. Ultimately, almost the unloading start of the conveyor motor is obtained. Voith Turbo GmbH with the coupling of the TV type is a potential producer of such couplings. The suppliers of this type of coupling on the Polish market are also companies such as Flender-Siemens with FV and FN clutches and (in the near future) Fasing (MOJ). Figure 13 shows the construction of one Voith 487 650 TVF series clutch. Voith couplings are built in several types, adapted to the specific working conditions of working machines. They differ mainly in their construction and size of their delay chambers.

Constant hydrodynamic couplings are protected by fuse plugs. Their purpose is to protect against the thermal overheating of the coupling and excessive pressure increase by releasing the working fluid.

Apart from hydrodynamic couplings with constant fluid filling in heavily loaded conveyors, clutches with an adjustable fill level of the working space are used. An example of such a clutch is shown in Figure 14 [13].

The initial start-up phase of the drive system with such a clutch is carried out without load (with the clutch disengaged). The hydraulic fluid is only supplied after the engine has been fully started, and the chain conveyor starts slowly from there.

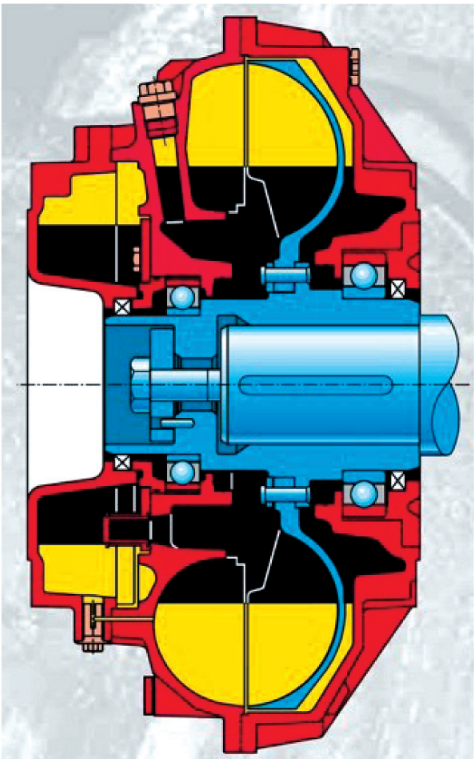

Fig. 13. Voith type 487 650 TVF clutch [12]

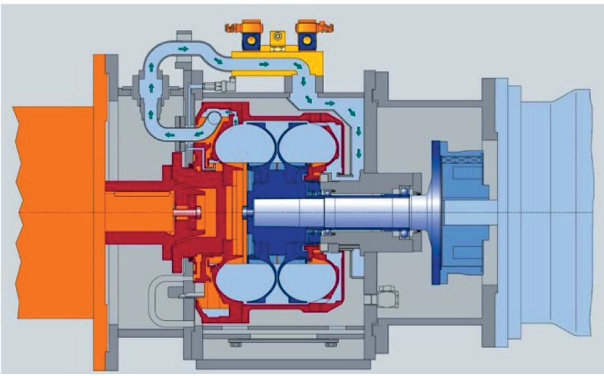

Fig. 14. Hydrodynamic coupler type DTPKWL 2 with adjustable water filling [13]

A wall-mounted floor conveyor equipped with adjustable-type hydrodynamic couplings moves into a steady state after reaching the working speed chain. The optimum size of the working space is 70% to 75% of the total capacity of the clutch when the conveyor is in operation [14].

When using this type of clutch, the working speed of the chain is reached about 30 s after startup, which is too long during times of frequent starts. This is a major disadvantage of this type of hydrodynamic coupling.

In the case of heavily loaded floor conveyors (where frequent couplings are expected), DTPW-type flow couplings [9] can be used. The design of this type of coupling was jointly developed by Voith and JOY. In this coupling, there is a continuous replacement of water coming most often from the fire pipe. Its volume in the clutch working chamber is constantly adjustable depending on the load condition of the conveyor. This clutch can work with approximately twice as much lubrication as a clutch with a constant filling.

In summary, hydrodynamic couplings are a common design that have been used in operational practice for several decades. They are characterized by a number of advantages, but their use is not devoid of disadvantages. This is why companies producing clutches for the mining industry sought new solutions.

The Halbach-Braun Company has proposed the construction of a multi-plate overload clutch (slip clutch). They can be installed between the motor and gearbox as well as at the transmission shaft of the transmission.

This type of clutch is located between the motor and the gear unit in series with a flexible coupling; e.g., insert. However, these clusters are very rare in the national mining industry [9].

Voith is also used in its SafeSet overload clutch (Fig. 15). They are used primarily in the mining conveyors of the American mining machinery manufacturer Joy Mining Machinery. In this case, there is also a slip in the clutch mechanism. Adjustment of the torque in takes place in its hydraulic system.

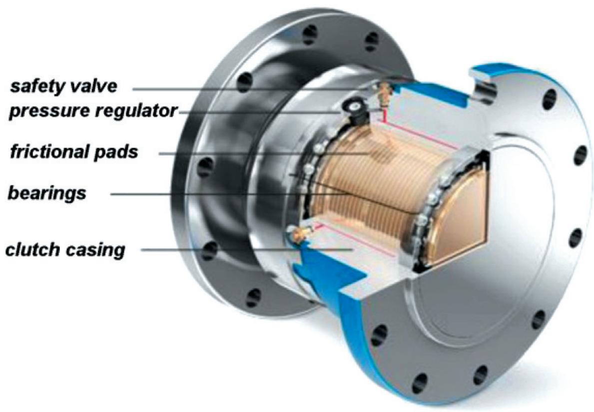

Fig. 15. Construction of Voith SafeSet overload clutch [15]

The Safesydor systems from Dorstener and the DBS from DBT and Dodge are used for a more--advanced ways of securing the drive systems from overload, difficult starting, and leveling of individual drives in the wall conveyor. In both cases, the safety components were directly linked to the gear unit.

In the first of these solutions, the planetary gear wheel of the first planetary stage was associated with a oil lubricated multi-plate clutch (Fig. 16).

This solution allows for both the easy startup of the conveyor and also protecting the drive system from overload during a fixed operation. In addition, it allows us to balance the power of the individual motors.

However, this system has not found much use in mining practice [9]. The disadvantages of this system are the high cost of production associated with a complex control system as well as the poor co-operation with two-speed motors.

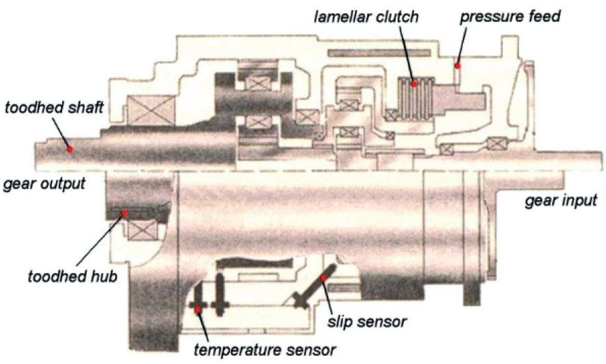

Fig. 16. Dorstener Safesydor system [9]

For floor conveyor drives, the CST (Control Start Transmission) system has been used since the mid-1990s. Contrary to the name, this solution is not only intended to facilitate the start-up of the conveyor, but through the control system and associated sensor systems, it is able to react to any load changes in the conveyor.

As with the Safesydor system, the CST drive system integrates two drive system components: the gearbox and clutch. They are placed in two interconnected permanent parts of the common enclosure. In one part, there is a planetary gearbox with a builtin CST clutch mounted on the output shaft. This is a wet multi-plate clutch with special ceramic linings (Fig. 17).

The other parts of the system (gray in Fig. 16) contain other components of the system, such as:

- high pressure pump, oil heat exchanger;
- hydraulic control, precision servo valve with smooth adjustment;
- pressure, temperature, and input/output speed sensor;
- electronic pre-treatment of measured values;
- PROTEC drive controller.

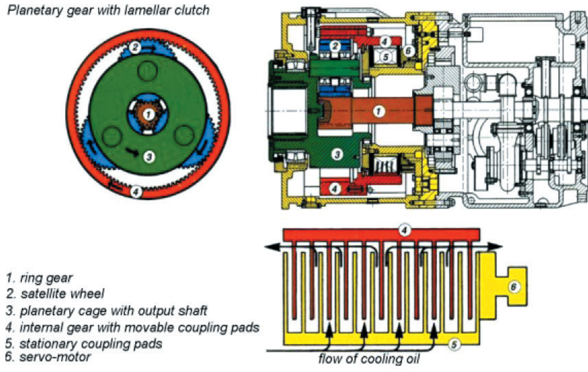

Fig. 17. Integrated CST system [16]

In the start-up phase, all motors of the floor conveyor are started. This is done without load. Only when the CST system is fully engaged is the oil supplied to the CST system. During this run-in phase, the oil pressure increases; therefore, the load on the motor is synchronized. When there is a difference in power consumption in the less-loaded drive, the pressure is increased, as a result of which the clutch disc clutches increase and the slip is reduced until the load is equalized. Conversely, if the conveyor drive is blocked, the device driver instructs the relevant actuators to completely disconnect all of the drives.

Apart from the undoubted advantages of the CST system, there are also disadvantages that make it rare in the Polish mining industry. This solution is characterized by a quite-complicated construction, which affects the price of its production and maintenance costs [17]. There, there is also a high demand for the technical culture of its use [9]. These negative features have made this solution much less common compared to hydrodynamic couplings.

The clutch constructions used in mining floor conveyors have been characterized by numerous advantages and disadvantages. Older designs are characterized by their simplicity, low production, and low operating costs; however, they do not meet the expectations that they face. Newer couplings meet these expectations, but they are distinguished by the increasing complexity of construction (which increases their production and service costs). Therefore, new construction solutions for couplings should be sought. For example, one such solution is the construction of the metal torsionally flexible coupling that has been developed at the Department of Mining Robotization and Mechanization of the Faculty of Mining and Geology at the Silesian University of Technology.

This component is made entirely of metal, which is a significant difference compared to the currently produced construction. Its idea, structure, and principle of operation have been described in the following references [18–20]. It is characterized by simplicity of construction and (consequently) its low cost of production.

Figure 18 shows a clutch view designed for a 400 kW electric motor. It is integrated with an insertion clutch that is located between the motor and the gear unit.

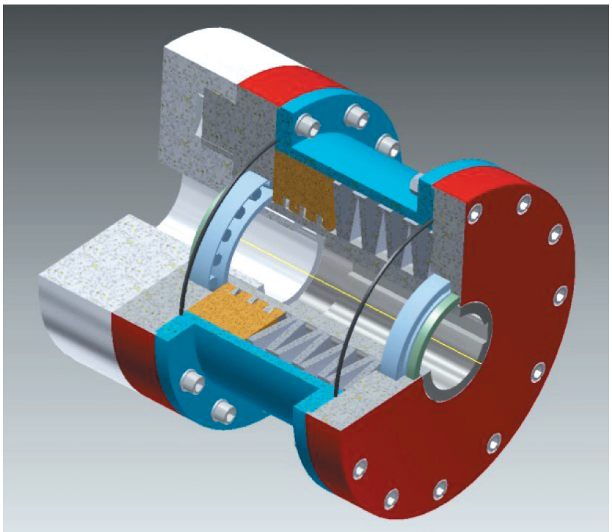

Fig. 18. View of solid metal clutch model designed for 400-kW floor conveyor drive system

The torsionally flexible metal clutch mechanism can also be located in the drive drum (Fig. 19). Integrating the two drive system components into one drive saves space. This is an original solution that has not been used thus far.

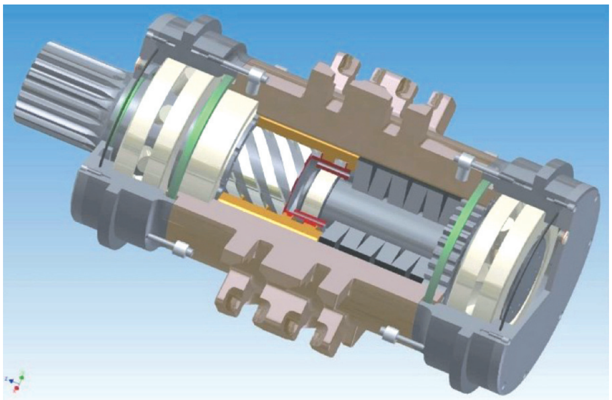

Fig. 19. Torsionally flexible metal coupling with drum drive of floor conveyor (power: 400 kW)

The overload protection of the drivetrain is also ensured by a proper chain coil chaining. This problem was solved at the Department of Mining Robotization and Mechanization of the Faculty of Mining and Geology at the Silesian University of Technology. Movement and vibration caused by the movement of the spoil in the gutters cause an elongation in the chain. The consequence of this phenomenon is a disturbance in the conveyor operation caused by the improper co-operation of the drum with the chain at the point of its descent. The solution to this problem is to apply the correct adjustment of the required chain tension to the operating conditions of the conveyor. This is done by shifting the auxiliary drive hull using a suitable control algorithm called ASTEN [21].

3.2. Belt conveyors

Belt conveyors are the next link in the conveyor system from the longwall.

In the conveyor belt drive system, the following technical solutions are used as overload protection (which occurs mainly during start-up) [22]:

- two-speed motors,
- thyristor starters,
- frequency inverters,
- use of DC motor,
- flexible couplings,
- hydrodynamic coupling,
- CST system.

As with scraper conveyor systems, the start-up of the conveyor belt is accomplished by using the appropriate starting devices. These units support the start-up phase of the conveyor by electrical or mechanical means.

The mechanical start-up assistance is carried out through a clutch mechanism. The simplest solution is to use a flexible clutch, but this solution is not suitable for long and overly inertial conveyors. The low torsional rigidity of such a coupling reduces the loading capacity of the loaded conveyor.

Belt conveyors also use hydrodynamic couplings, most often with constant filling. These are Voith system couplings T, TV, TVV, and TVVS [22]. Flow couplers with the adjustable filling of the TPKL system (Fig. 20) and DTPKL or their variants may also be used [22].

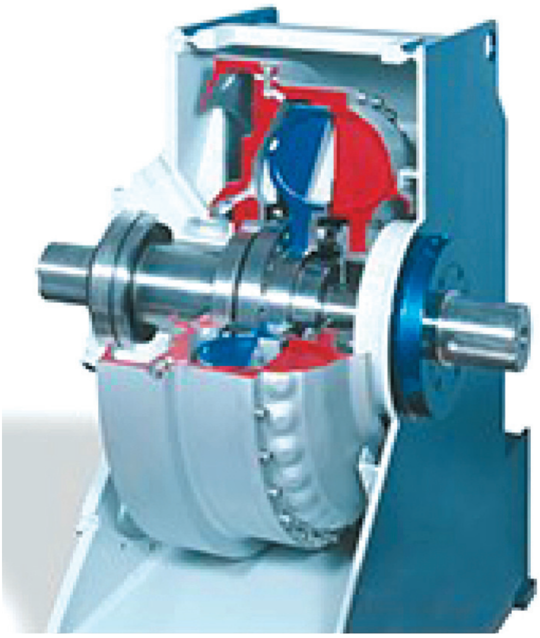

Fig. 20. Voith's TPKL flow clutch [15]

The CST artificial intelligence systems [22] described above are used for the startup of multistage tape conveyors of considerable length and inertia. This system is well-suited to work with the same type of drive in a conveyor equipped with drum intermediate drives, where the correct positioning of a drive with identical engine power is very difficult.

4. SUMMARY

Machines used in underground mining work under particularly difficult working and environmental conditions. This applies to the excavating and transporting machines in particular. In addition, modern mining saddles them with particularly difficult requirements, because they are characterized by high reliability and significant durability. Their failure-free operation depends on the continuity of mining in the mining plant.

The continuous increase in the efficiency of technological processes in underground mining (i.e., the efficiency of machines entering the mining cycle) makes the drive system most vulnerable to dynamically changing loads during operation, which is the most-important component of each mining machine. Its effectiveness depends on the efficiency of the machine.

In order to mitigate these unfavorable operating conditions in mining excavations, indirect and direct methods can be used to prevent overload occurring during the start-up phase and fixed work.

Indirect methods are related to the control system, where the engine parameters are controlled without blocking or overheating.

In direct methods, clutches of different construction are used. Cartridge couplings consist of durable components and have a simple construction and operating principle, but they have a lot of limitations. More-advanced systems such as CST, Safesydor, and popular hydrodynamic couplings have many advantages, but they no are also free of defects. This is why we are constantly looking for new solutions. One of them may be a metal torsionally flexible coupling which has been developed in the Department of Mining Robotization and Mechanization of the Faculty of Mining and Geology at the Silesian University of Technology. It has a much-higher torsional rigidity compared to the insert clutch couplings combining the simplicity of construction with them.

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