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Design, Manufacturing and Testing of Torque Limiting Feature in Flexible Disc Couplings

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***Abstract*: The paper presents the concept of use of torque limiting feature in flexible disc type of coupling for power transmission and to operate in continuous heavy-duty service and severe environments. A shear pin is a safety device designed to shear in the case of a mechanical overload, preventing more expensive parts from being damaged. It is analogous to an electric fuse. The shear pins are mounted at a pre-defined radius from the centre of the rotational axis of coupling. These pins are made of alloy steel carefully designed and machined to allow the shearing action when the desired breaking load is reached. Detailed design is carried out first by analytical method. CAD based drawings are done by using AutoCAD software. Fabrication of the shear pins with different groove sizes are carried out in CNC machine. The pins are then tested in Universal Testing Machine, and breaking loads for all sizes are noted, with the data of pins tested, the optimum size is compared with the analytical method, and is used in finishing the final design of the coupling. This design is used to connect electric motor and gearbox having rated power of 35537 HP at 1500 RPM.**

***Keywords*: shear pins, CAD, Hubs, Spacers and Adapters.**

1. Introduction

Certain types of machines require drives to operate in continuous heavy-duty service and severe environments. For example, steel rolling mills operate under the most severe conditions imaginable, applying tons of pressure on slabs of steel to squeeze them into long thin plates or sheets. These machines must withstand unpredictable malfunctions in their operation, such as a jammed line, that cause torque transmitted by the drives to jump sharply. Such malfunctions typically cause some drive components to suddenly stop moving, which imposes extremely high torque overloads on the equipment, leading to extensive damage and put the equipment out of commission for hours or days. Development of mechanical hardware for such type of applications is a challenging task for mechanical engineers. The task involves material selection, design, analysis based on strength and functional requirements, manufacturing, testing and proving the hardware. The purpose of torque limiting devices is to quickly react to these malfunctions and prevent the huge loads that would damage drive components. Flexible coupling is a device used to couple steel shafts. The coupling is used to transmit torque from one rotating machine to another. The purpose of a flexible coupling therefore is to permit transmission of desired power at the rated speed, while taking into account the misalignment that occurs and absorb the shaft resorting loads. It also ensures that the bearings in the rotating machinery are not damaged while transmitting the forces. All Metallic Flexible Disc Couplings consist of an assembly of components such as hubs, spacers, adaptors, bolts, nuts, washers, etc. The product is designed and manufactured, based on specifications for each application, for transmitting mechanical power between two rotating equipment's. The parts involved are manufactured from out of alloy steel and stainless materials, and these are machined to very high accuracies and close tolerances. Shear pin principle is a simple mechanism. The pin, typically fabricated from a softer material, inserts between two mating flanges. When an overload greater than the pin's shear strength occurs, the pin will break, or shear, releasing and thus protecting the mating components. This arrangement provides one of the most rigid connections between two rotating elements. The objective of this paper is to design, manufacture and testing of a shear pin unit for electric motor and gearbox application, where the peak torque produced by a line-to-line phase short circuit at minimum operating speed is 1230 KNm. It is inadvisable to strengthen the coupling to handle this condition because the transmitted peak torque exceeds the torque capacity of the coupling and gearbox components. The work involves structural design by analytical method, selection of materials, fabrication and testing of shear pins. The study of various flexible couplings used for power transmission revealed considerations for specific design for application in various fields. For heavy duty applications where unpredictable malfunctions occur, a mechanical sacrificial part is to be designed such that it shears at pre-determined torque, preventing more expensive parts from being damaged. These pins are located on a preferred radius on a flexible coupling. A shear pin fitted between two mating components of coupling acts as a mechanical fuse.

2. Literature survey

Flexible couplings are too often thought of as a piece of hardware, rather than a vital part of a power transmission system. Flexible couplings are often bought on price rather than suitability or functionality. Many applications of rotating equipment's do not require much thought about the coupling

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that connects the driver and driven equipment, but there are many applications that are critical and very sophisticated. These usually require custom designed couplings to accommodate the system. The applications that require custom designed couplings are not limited by horsepower or speed considerations, but are dictated by the need for a coupling that will provide dependable operation under specified conditions. Custom designed couplings are manufactured for specific equipment. Mehrdad Jafarboland and Mahmud Zadehbagheri presented that Non-modelling of flexible connections such as couplings and the belt-pulley do not show some real behaviors. In a coupling system of two electric motors the non-modelled fluctuation modes caused by flexible connections can disturb controller operation and cause undesired vibrations in a submarine body. They presented a dynamic model of flexible connections and a completed dynamic model of two different coupled electric models. A robust controller for the completed model is also amended so that the two controlling targets of a desired speed adjustment and an appropriate load division between the two motors with sufficient accuracy are achieved. Prof. R.S.Powar, Prof. N.S Deshmukh, Dr.S.D.Suryawanshi presented a new approach of flexible Coupling by the use of belts for flexing. The methodology includes use of flexible coupling having hub, flanges, bolts and belt. This coupling allows parallel, angular and axial misalignment. Modification in conventional coupling as a flexible coupling reduces its 6 weight and radial space for installation considerably. Also compared with previously available belt coupling the axial distance is reduced without compromise in its strength. And this coupling provides radial rigidity and angular flexibility. Bill Meier and Dave Edeson presented in their paper the use of torque monitoring couplings in order to know how critical equipment's are performing so that the intervals between scheduled shutdowns can be chosen appropriately in petrochemical and process industries. Dr. Hab. Inż. Krzysztof Filipowicz presented the construction metal coupling of high torsional flexibility and preliminary tests were to determine their characteristics. A. T. Tadeo and K. L. Cavalca presented the effects of the mathematical models of flexible couplings in rotating mechanical systems in terms of their vibrational behaviour. Their work shows the modelling of a mechanical rotor-bearing-coupling system, through the finite element method, used in the case to analyse the transverse vibrations of the system. Christian C. Wolford studied basic principles of various couplings and presented criteria in selection of dry type flexible couplings to replace existing gear couplings for petrochemical and process industries. Joe Corcoran studied the principle difference of torque transmitting capabilities between diaphragm and disc couplings. Metallic flexible-element couplings diaphragm and disc couplings rely on the flexure of metal to accommodate misalignment and axial displacement of shaft ends while transmitting torque. Diaphragm couplings accommodate flexure from the metal between the coupling's Outside Diameter (OD) and Inner Diameter (ID). Disc couplings accommodate flexure from the metal between adjacent bolts the flex elements that are attached to opposite flanges. Optimizing the flex elements produces drastically different capacities and characteristics in diaphragm and disc couplings of the same OD. Jon R. Mancuso compared the characteristics of diaphragm couplings versus gear coupling used in industrial gas turbine applications including applications for turbine to generator, turbine to compressors and also for turbine and accessory gears. He states that diaphragm couplings are more predictable and reliable than a gear coupling for most industrial gas turbine applications. Study of various flexible couplings reveals that there are very few literatures on overload protection for heavy duty applications. This reveals that designing for these applications is quite critical. The selection of shear pins is influenced by the following factors viz., geometry, mechanical strength, working conditions etc.

3. Overview of flexible disc coupling

The above figure (1) shows the formation of flexible disc coupling. The flexible disc coupling is of the dry laminated disc type in which flexibility is obtained through the deformation of the discs (blades) in the disc pack (flexible element). The disc packs are separated by a central spacer. There are limitations to the amount of deformation or misalignment that the disc packs can withstand in both the axial and angular directions and these limits are specified for the coupling. The individual discs are of a regular outer polygonal profile and are assembled into packs of designated thickness and secured by bushes and washers. Torque transmission and flexibility is accomplished by connecting the disc packs (element assemblies) through the bushed holes, on a common bolt circle diameter, by means of bolts which are alternately fixed to the driving and driven machine components.


Fig. 1. Flexible disc coupling

During operation the disc packs are subject to significant levels of both tensile and bending stresses resulting from the imposed torque, speed and misalignments. These stresses are all inter-related with a change in the level of one affecting the permitted limits of the other. With defined steady torque & speed this relationship focuses on the levels of misalignment. As such, changes in the level of axial deflection will alter the permitted level of angular misalignment. Since the disc couplings are torsion ally stiff and still flexible, they are a great solution for high speed applications. These couplings are more delicate than the average coupling and 18 can be damaged if misused. Special care should be taken to ensure that misalignment is within the ratings of the coupling. Flexible couplings project machinery from wear and premature breakdown. They can play a key role in extending the service life of the components they connect, and often without compromising machine performance. Basically, the coupling consists of three main components: Hubs, Spacers and Adapters, Flexible Elements and Connecting Fasteners. The spacer is the middle part of a coupling and is made up of forged alloy steels (which are the first heat treated). This is manufactured by turning process in the manual lathe machine; the adapter is the part which is connected to spacer on one side and hub in the other. But sometimes adapters may or may not be used and directly the spacer may be connected to the hubs, spacers and adapters are made of heat treated forged alloy steels. The flexible element is an assembly of cold rolled stainless sheets of very small thickness. These sheets are present on either side of the spacer. This is the most critical part of a flexible disc coupling, during transmission of torque from one machine to another there are various loads acting on the coupling. Connecting fasteners are the nuts and bolts used to connect the hubs, spacers and adapters. They are made of high strength alloy steel. These are manufactured on turning machine. There are two types of bolts namely attachment bolts and coupling bolts. Coupling bolts are those which are used to connect the sheet assembly with the spacer and adapter or hub. The remaining bolts used in a coupling (connecting adapter and hub) are known as attachment bolts.

4. Principle of flexible disc coupling

The above figure (2) shows the principle of flexible disc coupling. The coupling is torsion ally stiff and the transmission of torque is by tension. The transmission of torque takes place from C to B, A to F and from E to D. when the driving and driven shafts move, flexibility is achieved in the sheet assembly. The flexible sheet assembly has a polygon outer profile with a hole in between. The coupling bolts are made of stainless steel and are designed to transmit adequate torque. There are three types of misalignments in the coupling namely axial, radial and angular. Misalignments arise due to temperature variations, wear, wrong foundation etc., in all rotating machinery. Axial misalignment is the variation in axial distance between the shafts of driving and driven machinery. Angular misalignment is the angle between shafts and when the shafts are flanged, it is the angle between them when brought to a position of contact. Radial or parallel misalignment is the transverse distance between the two shaft center lines. Disc couplings can be used at speeds up to 10000rpm. Analytical calculations are performed to estimate the stress induced on coupling components such as Adaptors, Spacer and Attachment bolts. Calculations are performed to theoretically estimate the breaking load, numbers of pins and size of shear pin based on the inputs for the application. The selection of material in the design process is a key step. The Designer should have ready access of information on materials. An incorrectly chosen material can lead to failure of the whole equipment. Selecting the best material for part involves more than selecting a material that has the properties to provide the necessary performance in service. It is also connected with the processing of material into finished part. A poorly selected material can add to manufacturing cost and unnecessarily increase the cost of the product. Depending on shear pin material to be removed and geometrical accuracies desired on the pin, specific insert is selected. The most important feature in shear pin is 35°angle groove. This groove has to be machined in very controlled manner. Carbide insert with 35° included angle which is fixed to tool holder is selected for this purpose. This insert produces better finish on the part, allows faster machining and can withstand higher temperatures than standard high speed tools.

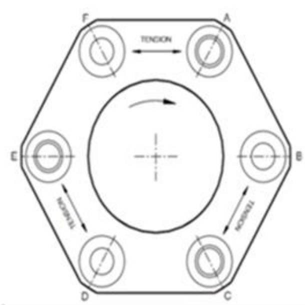

Fig. 2. Principle of flexible disc coupling

The thickness of chip is proportional to the federate and chip width proportional to depth of cut. The cutting speed is inversely proportional to the chip thickness. Inspection of jobs is done to check whether the pins are machined to the required size according to the drawing. The focus of the inspection process is on finding defects. Correct installation and alignment will insure long life and trouble free operation of the coupling must be checked for signs of damage, wear or fatigue and should be replaced if necessary. Next, the hardness test gives an idea of the resistance to wear of the pin material. This is important with respect to the components which have been built up and have to withstand abrasive wear. Hardness values can give information about the metallurgical changes caused by manufacturing operations.

5. Result

Fig. 3. Curve for groove size: ø23.8mm

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Fig. 4. Curve for groove size: ø24.0 mm

Table. 1
Shear load test results

Shear Load test for Test pin:				
S. No	Shear pin size(mm)	Breaking Load (N)	Cross head travel (mm)	Shear stress (N/mm^2)
1	23.5	267.74	3.2	601.824
2	23.8	286.96	4.2	634.321
3	24.0	287.7	3.12	663.492

6. Conclusion

Design, manufacturing and testing is carried out on shear pins. The new feature i.e. shear pin provides an accurate measure of value required to disconnect the Motor from the gearbox equipment. Replacement of shear pins requires very less time during shut down time. In overall view reducing the downtime cost of the unit and can be positioned anywhere on the drive train. Machining of shear pins is carried out using CNC lathe in controlled specifications and hardness test is carried out using Rockwell Hardness testing machine, and observed that the pin materials are in specified conditions. From analytical calculations the breaking load achieved is 276 KN and size Ø24 mm. Shear test is performed for three shear pins in Universal Testing machine, and corresponding results were noted, for the shear pins with groove size of Ø23.8 mm and Ø24.0 mm, the corresponding breaking load (N) are 287 KN and 287.7 KN respectively.

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