Failure analysis of flexible couplings by self-heating

R Grega¹, M Kacir¹, J Krajnak¹

¹Department of KaDI, Faculty of Mechanical Engineering, Technical University of Košice, Letná 9, 04001 Košice, Slovakia.

Abstract. Flexible couplings are applied in mechanical systems to reduce torsional vibrations. Failures in the flexible parts of the couplings are often incorrectly attributed to overloading of the couplings. The goal of the article is to prove by experimental analysis that self-heating occurs in flexible couplings. The self-heating of the flexible coupling and the consequent increase in the temperature of the flexible part is the cause of the failure. Experimental identification of self-heating was performed on three types of flexible couplings. Although these couplings are design different, they are used for a nominal torque of 150Nm.

1. Introduction

The most widely used transmission of mechanical energy is the use of rotational motion. Devices transmitting rotary motion must be functionally connected to each other. Shaft couplings are used to connect devices transmitting rotary motion [1], [2]. Shaft couplings also have other supporting tasks in mechanical systems. Supporting tasks are the elimination of expansion joints, protection against overload, ensuring the start-up of the mechanical system, etc. For many types of couplings, the supporting tasks are as important as the transmission of the rotary motion itself. A special group of couplings consists of flexible couplings [3], [4].

The flexible shaft couplings must be able to transmit rotational motion, but above all they must protect the mechanical system from torsional vibrations. This protection against torsional vibrations must be provided in a large range of operating modes and operating speeds, not only in transient states during start-up and stopping of the mechanical system [5] [6]. Another additional feature of flexible couplings, which results from their construction, is the elimination of expansion inaccuracies caused by the production and assembly of individual parts of the mechanical system [7] [8].

The method of application of the flexible coupling in order to protect the mechanical system against torsional vibrations can be characterized in two methods. The first method is to apply a flexible coupling in a mechanical system so that we achieve its tuning. It is a design of a flexible coupling based on input parameters. After the design of the flexible coupling and its application to the mechanical system, it is not possible to change the parameters of the flexible coupling [9], [10]. The second method is the application of a flexible coupling in a mechanical system, so we would achieve it’s continue tuning. For this method of application, it is necessary to use torsional vibration tuners that are able to change their parameter during the operating mode of the flexible coupling [11], [12].

In both cases, however, the protection against torsional vibrations uses the principle of changing the natural frequency of the mechanical system. By changing the natural frequency of the system, a change in the resonant area from the main excitation frequency is also achieved [13], [14]. It is important that the resonance from the main excitation frequency (resonance excited by the main harmonic component of the load torque) was outside the operating range. Thus, the resonance is required to be in the speed range lower than the operating speed range of the mechanical system. The
such an application, during a quick start or stopping the mechanical system will not allow the torsional oscillation to generate sufficient fault energy. It is in this resonant area that one of the basic properties of flexible couplings is used, namely damping [15], [16].

The design of the flexible couplings must transmit the rotational movement and at the same time ensure the tuning of the mechanical system. Although the design of flexible couplings has undergone extensive development, it is possible to establish basic design features for all flexible couplings. Each flexible coupling consists of three basic parts. The first part is the drive part, or the primary part. This part is usually a disc or flange which allows the flexible coupling to be attached to the drive machine. The second part is the driven or secondary part. This part is installed on the driven equipment or on the drive shaft of the driven machine. Usually this part is made as a rotating disc or flange. Between these two parts there is still a third part of the flexible coupling, which is a flexible member. The flexible members can be of various designs. Various materials are used for the design of flexible coupling parts, such as e.g. ferrous and non-ferrous metals, plastics, rubber, composite materials and various gases and liquids [17], [18].

Current trends in the field of mechanical system dynamics also require innovation in the design of flexible couplings. Various special types of flexible couplings are created, which are used mainly in the automotive industry. Dual-mass flywheels are such an example of successful innovation of flexible couplings. Their distribution is such that the metal flexible element connects the primary and secondary masses, which allows a large angle of twist. [19], [20]. The flexible element usually consists of a rubber or steel spring.

We can also consider as a successful innovation of flexible couplings those types of flexible couplings in which it is possible to adapt their dynamic properties to the operational requirements of the mechanical system during their operating life. Such flexible couplings include, in particular, pneumatic flexible couplings. Pneumatic flexible couplings, especially in combination with control systems, make it possible to effectively change the dynamic conditions in the mechanical system. Such targeted changes in dynamic properties during the operation of the device are called continue tuning of the mechanical system [21], [22].

Pneumatic flexible couplings, which will be equipped with a system for controlling their properties during the operation of the mechanical system, are called pneumatic torsional vibration tuners. Despite the extensive knowledge in the field of flexible coupling design, defects often occur on the flexible parts. In many cases, the cause of these faults has been identified as clutch overload. Such fault identification can also be incorrect. In this paper, we want to point out the fact that torsional vibrations cause the flexible couplings to heat themselves and the increase in temperature leads to damage to the flexible elements and loss of function. This statement is confirmed by several authors involved in the development of the dual-mass flywheel (DMFW). As stated in the "A. Albers: Advanced Development of Dual Mass Flywheel (DMFW) Design - Noise Control for Today's Automobiles" [23] in the case of DMFW there is a significant increase in temperature by spontaneous heating and consequent change in the functionality of DMFW. The goal of the article is to point out the self-heating of flexible couplings in mechanical systems and to prove that self-heating is the initiator of the failure of the flexible part of the coupling.

2. Defining research problem

The incorrect design of the flexible coupling can cause serious failures of the coupling itself, but also of individual devices in the mechanical system. Initial failures of the couplings usually result in the formation of cracks or inadequate deformations of the flexible parts. Interestingly, such faults are often attributed to clutch overload faults. We want to prove that improper application of a flexible coupling can cause its self-heating, which has a direct impact on the temperature rise in the coupling. An increase in the temperature in the coupling will initiate the formation of a crack or deformation of the flexible part, which is the start for the failure of the coupling.

In FIG. 1 there are three different types of flexible couplings A) B-flex RB 116-4, B) Periflex PNA 10R, C) Gurimax GVW 100. These three types of flexible couplings belong to very common types and
are part of many mechanical systems. Experimental research to identify self-heating will be performed on these three types of flexible couplings.

![Flexible Couplings](image)

**Figure 1. The flexible coupling**

In addition to the examined couplings, it should be noted that the experiment will be performed within the recommended load ranges of the manufacturers. The recommended operating temperatures for the individual flexible couplings are as follows: Coupling B-FLEX flexible part is made of natural rubber and can work at temperatures ranging from -30 °C to +70 °C, Periflex PNA for the used flexible part material, flexible coupling can work at temperatures ranging from -20 °C to +80 °C and the Gurimax flexible coupling has a flexible part made of polyurethane with a Shore 90A hardness. It is electrically non-conductive, oil resistant and usable for temperatures in the range from -30 to +100 °C.

3. *Experimental solution of the problem*

The partial oscillation method was used to identify the self-heating of the flexible couplings. In this method, the flexible clutch does not rotate, but is oscillated by a variable torque component. This variable component is simulated by oscillating. For the oscillation method, a device is used, the model of which is shown in Fig.2. The test equipment consists of an electric drive motor, an oscillating arm and a brake.

![Testing Device](image)

**Figure 2. The testing device**

The design of the test equipment allows testing in the range of oscillation frequencies from 0 to 100Hz. The oscillating range is possible from 1 ° to 8 °.

The measurement methodology was determined as follows:
1. The oscillation frequency was set at 12Hz, which represents a clutch speed of 720min⁻¹. This frequency was determined on the basis of application practice.
2. The couplings under investigation differ in their design. Despite the different design, all examined couplings have the same Nominal torque $M_N = 150\text{Nm}$. In order to make a comparison with the result, the oscillation range for each clutch was determined as the torsion that would produce the torque at 20% load at nominal torque. This means that the B-FLEX and Gurimax couplings were oscillated at 1.25° and the Periflex PNA coupling was oscillated at 2°.

3. The duration of the experiment is 2 hours and 19 minutes, which is at least 100,000 operating cycles at the oscillation frequency.

4. The experiments were performed at an ambient temperature of 20 °C.

5. A Raytek Profitemp ST80XB ProPlus non-contact temperature sensor (-32 °C±760 °C), ± 1%, was used for temperature measurement.

6. A FlukeTi25 thermal imager (-20 °C±350 °C), ± 2%, was used to visualize the temperature conditions.

4. Results of experimental measurements

According to the specified loading conditions and, experimental measurements were performed to identify the self-heating of flexible couplings. In FIG. 3 is a course of temperature rise in the flexible part of the B-FLEX type coupling. As we can see from the course, the temperature rise is nonlinear and a steady value is not reached until the second half of the measurement time of the experiment. In FIG. 4 is an image from a thermal camera on which we can observe the propagation of heat from the flexible part to the other metal parts of the coupling. Heat is transferred from the flexible part to the metal part and from the metal part of the coupling the heat is dissipated to the surroundings.

![Figure 3](image1.png)

**Figure 3.** The course of temperature of B-FLEX type coupling

![Figure 4](image2.png)

**Figure 4.** The image of self-heating of B-FLEX type coupling from a thermal imager
In FIG. 5 is a course of temperature rise in the flexible part of a Gurimax type coupling. As from the course we can see the increase in temperature is immediate after loading and a steady value is reached in a very short time of the measurement time of the experiment. In FIG. 6 is an image from a thermal camera on which we can observe the propagation of heat from the flexible part to the other metal parts of the coupling. As can be seen from the picture, in this design of the coupling there is no heat transfer from the flexible part to the other parts of the coupling.

![Figure 5. The course of temperature of Gurimax type coupling](image.png)

In FIG. 7 is a course of temperature rise in the flexible part of a Periflex PNA type coupling. As can be seen from the course, the temperature increase is gradual and non-linear after loading and a steady value is reached in the first third of the measurement time of the experiment. In FIG. 8 is an image from a thermal camera on which we can observe the propagation of heat in the flexible part of the coupling. As can be seen from the figure, in this design of the coupling there is a very small and gradual transfer of heat from the flexible part to the other parts of the coupling. It is interesting that the flexible part of the coupling can be divided into temperature zones, between which heat transfer takes place.

![Figure 6. The image of self-heating of Gurimax type coupling from a thermal imager](image.png)
Figure 7. The course of temperature of Periflex PNA type coupling

Figure 8. The image of self-heating of Periflex PNA type coupling from a thermal imager

5. Discussion and Conclusion
The experiments were performed on three types of flexible couplings, which differ in design. The obtained results confirmed the assumption that due to the load, the flexible couplings self-heat up. As it is possible to analyze from the temperature profiles in the flexible parts of the couplings, the highest temperature is reached by the flexible parts of the B-FLEX type coupling. With this type of coupling, it also takes the longest time for the temperature to stabilize. The lowest temperature was measured on a Gurimax coupling. At the same time, this temperature and needed the lowest time to stabilization. An interesting view from the thermal imaging camera Fig.6 on heat dissipation. Although the temperature is lowest in this coupling, there are locally exposed areas with very high temperatures. The torsional vibrations cause the elastic elements to self-heat as a result of which the temperature in the elastic part of the coupling increases. This increase in temperature can attack the permissible temperature ranges of the clutch application range. We can state that the goal of the paper has been fulfilled.

In FIG. 9 are flexible parts of the tested couplings. Red arrows indicate emerging cracks and deformations that were caused by the coupling self-heating. These cracks and deformations are the basic initiator of the failure of the flexible part of the coupling.
Experimental testing of three types of flexible couplings has shown that the couplings self-heat up and subsequently also initiate failure cracks. It is essential that research into the self-heating of flexible couplings continues, thus reducing the risk of failure of flexible coupling parts.

Future research in your workplace needs to focus on three topics in the area of flexible couplings:

1. Research of the design of the flexible member in order to optimize its design for the temperature distribution evenly in the coupling parts.
2. Research of the relationship between the properties of a flexible coupling and the self-heating of a flexible coupling.
3. Research of the properties of the used materials of flexible parts of the coupling for self-heating.

6. References

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