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TRANSIENT BEHAVIOUR OF A SPRAG-TYPE OVER-RUNNING CLUTCH: AN EXPERIMENTAL STUDY

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1. INTRODUCTION

Sprag-type over-running clutches are used in various mechanical systems such as the air turbine starters of jet engines. These devices have been studied both theoretically and experimentally [1] to explain unexpected shaft ruptures.

As pointed out in reference [1], sudden engagement, after a sliding phase of the clutch, can lead to a pop out of sprags. In reference [2], a theoretical model is developed for studying possible sliding effects during engagement. The dynamic behaviour of the assembly, when engaged, is considered in references [3–6]. The experimental results reported confirm the highly non-linear nature of the damping and stiffness characteristics of these mechanisms. In reference [7], a non-linear stiffness model associated with the introduction of sprag-induced friction allows simulation of the dynamic behaviour of sprag-type over-running clutches during both engagement and engaged phases.

The objective of this study is to demonstrate the possible effects of sliding during the different running phases, by considering three simple experimental analyses. The results obtained highlight different configurations which could lead to rupture.

The first experiment shows a possible short sliding phase during the engagement process. Consequently, engagement becomes effective very suddenly, when the static rotational speed is greater than the engine seed, inducing over-torque on the shaft. The second and third experiments highlight two different behaviours induced by external excitation applied through the shaft. A harmonic exciting torque, whose amplitude is lower than the nominal transmitted torque, induces a continuous sliding effect. The starter speed becomes greater than the engine speed, a configuration that can lead to over-torque, as reported previously. When the harmonic torque amplitude is greater than the nominal torque, sliding in the counter-rotating direction occurs. As the starter is irreversible and considering the drastic inertia of engines, this configuration also leads to over-torque on the shaft.

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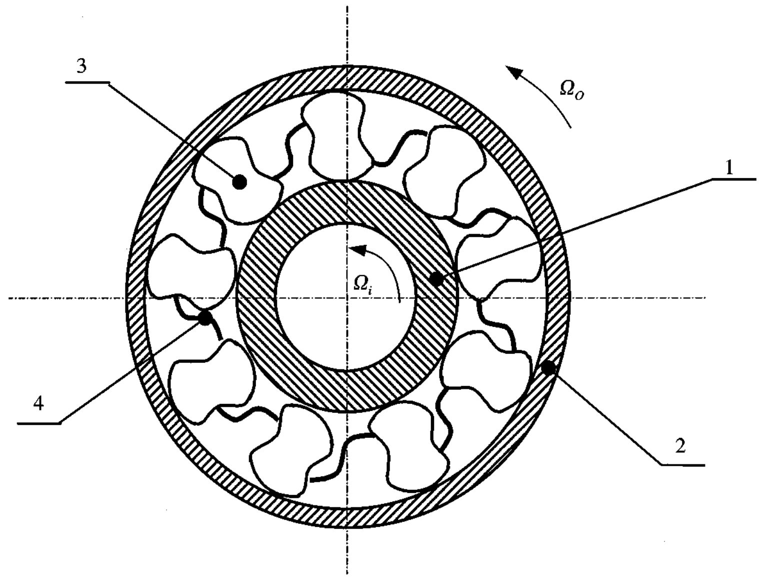

Figure 1. Description of an over-running sprag clutch.

2. DESCRIPTION OF THE SPRAG-TYPE OVER-RUNNING CLUTCH

The free wheel, sketched in Figure 1, is composed of sprags (3) mounted between two races (1) and (2). Springs (4) ensure contact between the sprags and races. In a jet engine starter, the outer race (2) is linked to the engine by a short shaft while the inner race (1) is linked to an air turbine via a reduction gear unit.

3. EXPERIMENTS

3.1. GENERAL DESCRIPTION OF THE EXPERIMENTAL SET-UP

The set-up developed is described in Figures 2 and 3. The free wheel considered can transmit a maximal torque of 20 N m. The outer race (1) is linked to the supporting frame via a torquemeter (3). The inner race (2) is fixed to a shaft mounted on bearings and its motion is measured by an angular potentiometer (4) located at the shaft's end.

3.2. EXPERIMENT 1—ENGAGEMENT

The goal here is to identify a possible sliding phase during engagement. The inner race (1) is moved under rotation by using a training mass (5) and stopped when a beam (7), fixed to the shaft end, comes into contact with a pre-stressed spring (6). Race (1) is moved in the coupling direction, simulating an engagement process.

The results measured are presented in Figures 4 and 5, for the first 0·08 s. From 0 to 0·029 s, the wheel is free. At 0·027 s the spring is released and engagement begins at 0·029 s when the inner race speed is equal to zero. Figure 5 shows that the torque is transmitted only $1{\cdot}5 \times 10^{-3}$ s after the speed became nil.

On examining the curves associated with the transmitted torque and with the angular displacement, seen in close-up in Figure 5, it appears that torque transmission begins when

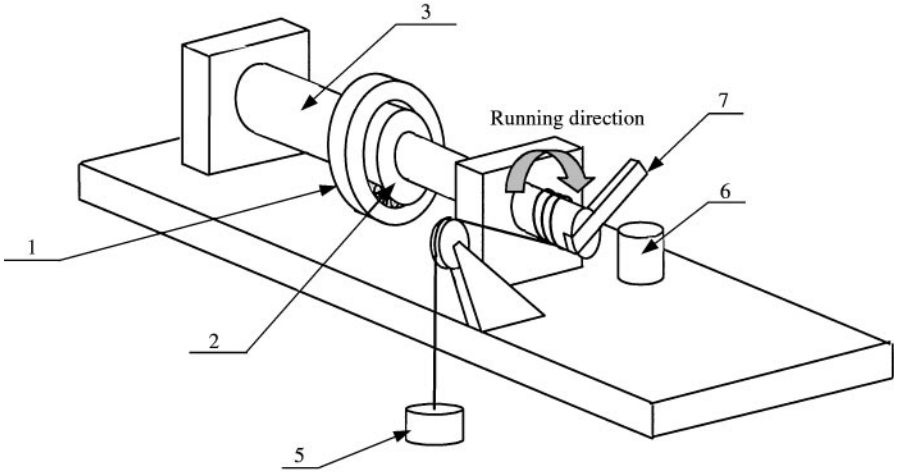

Figure 2. Experimental set-up no .1

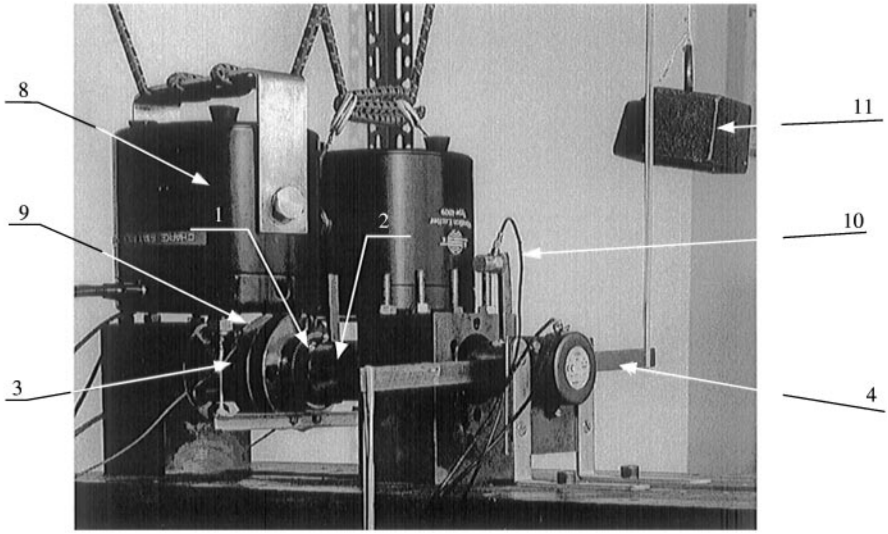

Figure 3. Experimental set-up no 2.

the inner race has rotated by 0·1 rad. This delay is associated with a sliding phase at the beginning of the engagement.

It should be pointed out that the inner race speed is about 100 rad/s when the torque begins to be transmitted. This configuration can induce significant over-torques on the shaft line of real systems and could explain unexpected ruptures.

3.3. EXPERIMENTS 2 AND 3—ENGAGED MODE

These experiments are aimed at illustrating possible sliding effects during the engaged mode, due to an additional vibratory environment. The wheel is now engaged with

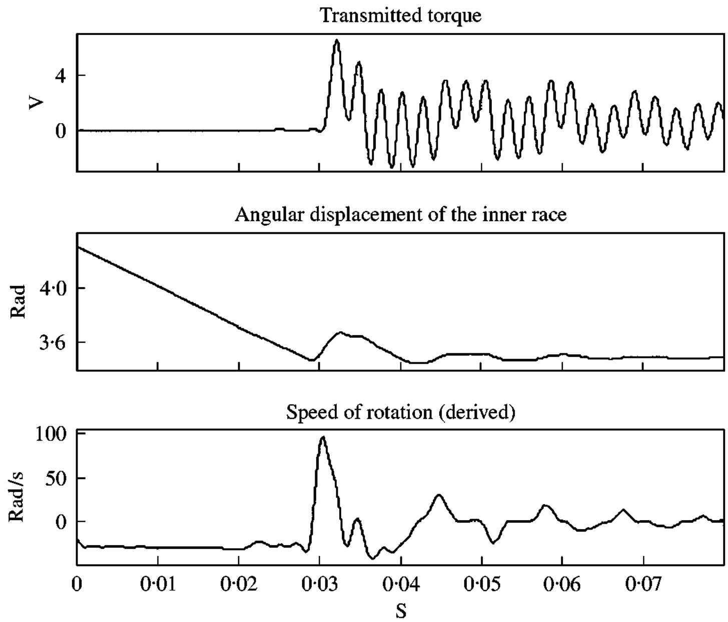

Figure 4. Transient response.

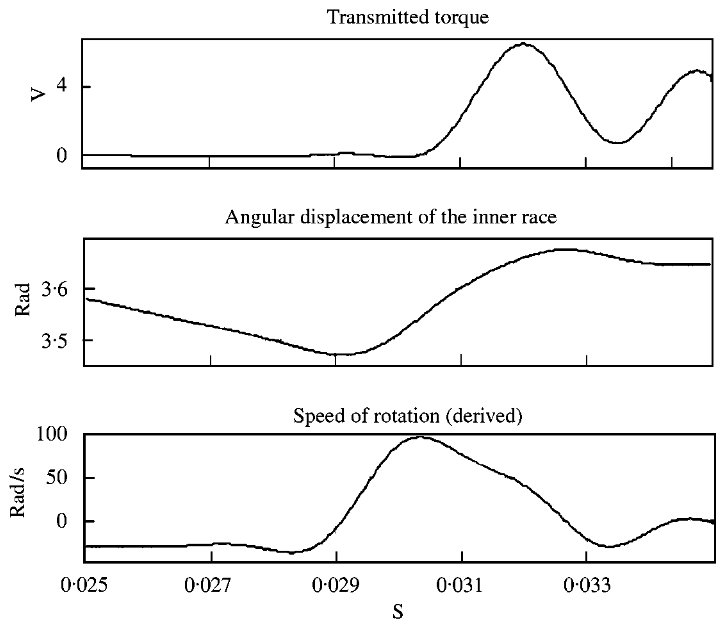

Figure 5. Zoom of Figure 4 until impact.

a constant torque applied to it. This torque is obtained using two identical masses (11) linked by two identical rigid beams to the shaft fixed to the inner race. The dynamic excitation is applied using two electrodynamic shakers (8) which exert a sinusoidal torque on the outer race (2). A sensor (9), measures the excitation force and an accelerometer (10), fixed to the inner race, gives the transmitted angular displacements.

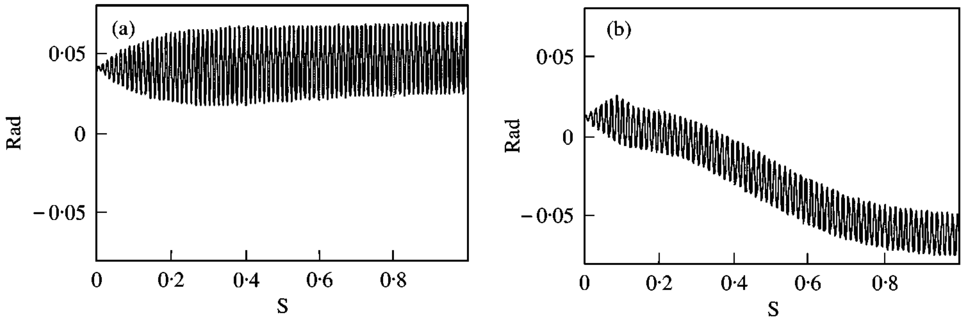

Figure 6. Angular displacement of the inner race. Torque to: (a) 16·6 N m; (b) 3·34 N m.

A frequency response, performed for two different constant values of the steady torque, gives the natural frequencies of the engaged wheel. For a constant torque of 3·34 N m, the natural frequency is 72 Hz while, for a torque of 16·6 N m, the natural frequency is 92 Hz. These results confirm the non-linear behaviour of the system.

The angular displacement of the inner race, for a steady torque of 16·6 N m and a harmonic torque of 8 N m at 92 Hz, is presented in Figure 6(a). Sliding appears to occur in the same direction as the applied steady torque. After 0·8 s, the sliding leads to a displacement of the inner race by about 0·01 rad. The same phenomenon predicted by the numerical model presented in reference [7], appears to be very sensitive to the friction coefficient between sprags and races. At the beginning of the engagement phase, the contacts are lubricated and the associated friction coefficient is quite low. The friction of sprags on the inner race progressively eliminates the lubricant and then, due to an increase of the friction coefficient, reduces and stops sliding. Then, engagement can occur when the speed of the inner race is much greater than the speed of the outer race, inducing significant over-torque.

The last test is performed for a steady torque of 3·34 N m and a harmonic exciting torque of 8 N m at 72 Hz. The associated angular displacement of the inner race is reported in Figure 6(b). Here, sliding occurs in the opposite direction compared to the steady torque direction. After 0·8 s, this sliding leads to an inner race displacement of about 0·05 rad. This phenomenon can be explained by a succession of engagement and free wheel phases. In fact, when the outer race is moved in the same direction as the inner race, due to the harmonic torque, the system behaves in free wheel mode and in this case the outer race runs faster than the inner one. After a semi-period, the harmonic torque moves the outer race in the opposite direction compared to the inner race and, consequently, engagement occurs. Then after each period, an angular offset is observed between the races.

These successive engagements and disengagements can have a significant effect on the life of the system.

However, it should be pointed out that this phenomenon requires a harmonic torque greater than the nominal steady torque, a situation which should hardly ever occur in real systems.

4. CONCLUSION

The objective of this study is to point out and quantify, using simple experiments, the possible relative sliding effects between sprag-type races of running clutches.

An initial sliding phase was identified at the beginning of the engagement phase. This effect is linked to sprags sliding on the inner race. A second type of sliding is observed when the system is engaged and excited by a harmonic torque at the natural frequency of the engaged wheel. A harmonic torque whose amplitude is lower than the steady torque value leads to sliding when the friction coefficient is low. In the case of high accelerations, both sliding phenomena could induce a significant difference of speed between races during engagement, thus explaining unexpected ruptures.

When the harmonic torque amplitude is greater than the steady torque value, sliding appears in the opposite direction. Thus, due to successive engagement and disengagement, this phenomenon could also induce significant over-torques in the shaft.

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