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Finite element analysis of automotive cushion discs

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ABSTRACT

We are interested in an automotive waved cushion disc located in the clutch system, inside the clutch disc. After gearshift and during the clutch re-engagement, the cushion disc allows to transmit a progressive torque through its axial stiffness. In order to optimize the correlation between numerical and experimental results, we propose to perform a finite element model that allows us to predict the behavior of the cushion disc under axial load. In this purpose, we will study the influence of modeling parameters and geometrical variability on the load deflection characteristic curve of the disc.

1. Introduction

The rotational motion in automotive engineering is difficult to master because it involves a lot of phenomena like inertia, friction, thermal effects, shocks between mechanical parts, vibrations, etc. In a vehicle, rotary motion is transmitted between the engine and transmission by a clutch system. The function of the clutch is to produce a soft gradual increase in the angular velocity of the driven shaft until full coupling is achieved. Then the clutch acts like a permanent coupling, transmitting the engine motion to the wheels [1]. The necessity of coupling or decoupling the engine and transmission during gearshift induced the development of mechanical components that aim to soften the contact occurring during the re-engagement of the rotational motion. This allows to preserve mechanical parts from shocking each other, increasing the lifespan of the engine and improving the driver's comfort. Conventional clutches include electromagnetic clutches [2,3], gear clutches [4,5], friction clutches [1], overrunning clutches [6,7] and centrifugal clutches [8]. Car manufacturers requirements for greater power transmission, lightweight, low cost design, smaller design space, high comfort and high effectiveness lead to develop new clutches mechanisms such as ultrasonic clutch [9] or piezoelectric clutch [10]. Nevertheless, today's passenger cars and light trucks are now almost exclusively equipped with conventional friction clutches (i.e. diaphragm spring clutches). In this work, we only consider dry friction clutches. It is composed of the clutch disc, the flywheel, and the mechanism, which is itself composed of a cover, a diaphragm spring, and a pressure plate (Fig. 1). When the engine rotates freely (no gear engaged) no torque is transmitted because the clutch disc is not in contact with the mechanism and rotates freely (Fig. 1). When a gear is engaged, the clutch disc is compressed by the diaphragm spring between the pressure plate of the mechanism and the flywheel transmitting the rotary motion and the torque to the mechanism and thus to the wheels.

In the field of clutch systems a lot of research has been done for a better understanding of mechanical phenomena. During the clutch engagement manoeuvre, sliding contact occurs between the pair of clutch facings mounted on the clutch disc and the counter faces belonging to the flywheel and the pressure plate. The transmitted torque is proportional to the overall coefficient of friction which depends essentially on temperature, normal pressure load and relative sliding velocity. In sliding contact systems such as clutches, extreme thermal environments arising from short period of time at varying sliding speed can produce unfavorable coupled thermomechanical effects [11]. Surface cracks [12], permanent deformation leading to localized high temperature at the contact zones, named hot spots, have been investigated [13,14]. Good performances of the clutch facings material are required in order to operate engagement and to avoid fading phenomenon which is due to a decrease of the friction coefficient according to temperature [1]. This implies a demand for improved mechanical and thermal stability, high wear resistance, high stability of frictional performance independently of varying operating conditions. As a consequence, the performance limits of organic materials are surpassed. Therefore, new friction materials such as metallic or ceramic composites have

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been developed and studied [15,16]. Vibro-impacts in manual transmissions are of critical concern to clutches manufacturers based on noise, vibration and reliability considerations. This phenomenon is often perceived as the gear rattle problem [17,18]. The clutch capability in reducing gear rattle noise has been theoretically investigated with reference to the influence on the phenomenon exerted by some clutch parameters, such as multi-valued spring, dual mass flywheel and hysteresis rates [19]. Audible disturbance known as automotive squeal noise observed during the sliding phase of clutch engagement has been largely studied [20,21].

As seen above, the necessity of coupling or decoupling the engine and transmission during gearshift induced the development of optimized clutch components that aim to transmit the torque between the pressure plate and the flywheel. In this work, we investigate the behavior of the clutch disc (Fig. 2). It allows a soft gradual re-engagement of torque transmission. This progressive re-engagement obtained by the clutch disc characteristics in the axial direction preserves the driver's comfort and avoids mechanical shocks. It also plays the role of a damper through the springs disposed around the hub. They enable the clutch disc to filter the torque variations of the combustion engine (Fig. 2).

The axial elastic stiffness of the clutch disc is obtained by a cushion disc (Fig. 3(a) and (b)) which is a thin waved sheet, located between the two facings and fixed by rivets. It acts like a spring allowing a soft gradual re-engagement. This nonlinear axial stiffness is obtained by cutting the cushion disc into paddles and forming them to get the wavy shape (Fig. 4).

The nonlinear axial elastic stiffness of the cushion disc is described by the cushion curve (Fig. 5). This load–deflection curve gives the axial load versus axial displacement obtained by compressing a cushion disc between two flat pressure plates. This experimental test validates a cushion disc. The wavy shape of the disc is the key element for obtaining this progressive cushion curve [22].

The cushion disc participates to the driver's comfort during the clutch pedal operation. The correlations between biomechanical

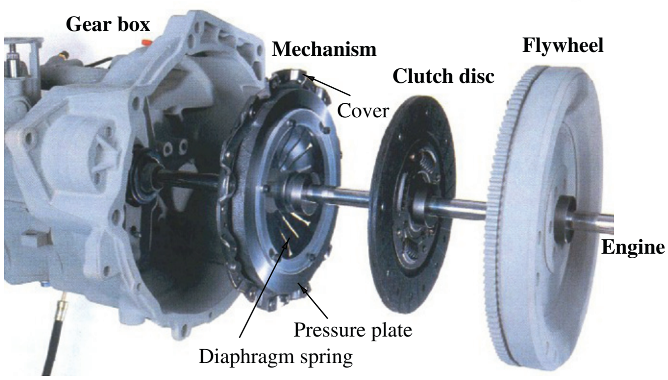

Fig. 1. View of the clutch. The clutch disc is crushed between the mechanism pressure plate and the flywheel to transmit the torque from the combustion engine to the transmission.

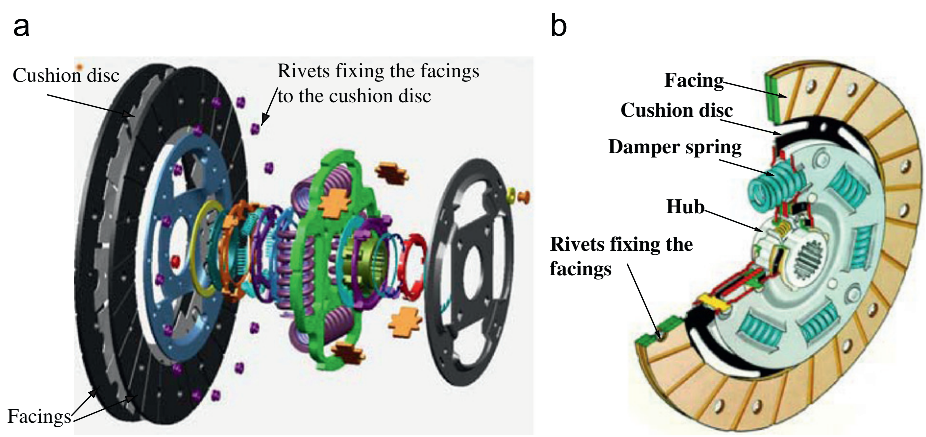

Fig. 2. Detailed design of the clutch disc: (a) exploded view, (b) complete view.

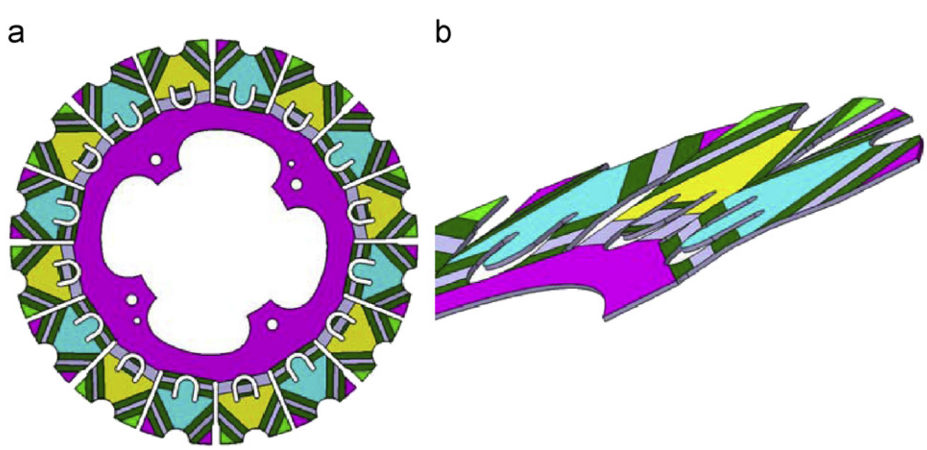

Fig. 3. Cushion disc: (a) front view of the studied cushion disc composed of 16 paddles, (b) cut view of the cushion disc.