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# Receptance based structural modification in a simple brake-clutch model for squeal noise suppression

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ABSTRACT

Unlike brake squeal, brake-clutch squeal has rarely been studied, even though the cause of squeal noise is identical – dry friction acting at the contact interface. In this paper, a combined theoretical and experimental study is reported on squeal noise of a brake-clutch. On the theoretical side, a receptance-based inverse dynamic method is adopted to identify the mass or stiffness required to split the coupled modes of a brake-clutch model to achieve noise suppression. On the experimental side, the theoretically identified stiffness is implemented on the brake-clutch test rig in the form of a grounded spring and it is thus shown that the actual structural modification has removed the squeal noise. This is the first time that a theoretically derived structural modification is made on a brake-clutch model and shown to be able of completely suppressing actual squeal noise. This study establishes a way of suppressing friction-induced high-frequency noise through structural modification.


## 1. Introduction

Squeal is a major concern in industrial brake-clutch applications because of issues of compliance with current occupational health legislation [1]. Despite the fact that the techniques used for squeal prediction in automotive brakes can be extended to analyse brake-clutch squeal, there is a need for a specific model that captures the distinctive features of this application, such as the ring shaped contact area and the asymmetric boundary conditions.

Typically, the role of a brake-clutch is to control the power transmission in a punch-press (Fig. 1(a)) by a series of alternating braking and clutch engagement operations. When the clutch is engaged, it forces the flywheel and the shaft to spin together; in turn, when the brake is engaged, it couples the lining holder on brake side with the rotor to stop the system (Fig. 1(b)). For safety reasons, at rest position the brake is engaged thanks to the force exerted by some springs and it is necessary to apply either pneumatic or hydraulic pressure to start the clutch engagement operation. Accordingly, contact stiffness is different on each side due to the two different pressure application methods, the springs or the pneumatic pressure.

Unlike in automotive brakes, the contact in brake-clutches occurs in a ring shaped area. Another difference is that the application time of the normal force is much shorter in a brake-clutch than in an automotive brake, lasting only a few milliseconds. It is for this reason that brake-clutch squeal is short lived even if it reaches high sound pressure values.

Several simplified brake squeal models can be found in the available literature, specially regarding automotive brake systems, either lumped [2] or distributed parameter models [3], or finite element models [4,5], with many of them validated by experiments [6]. A comprehensive review of model types for brake squeal can be found in [7].

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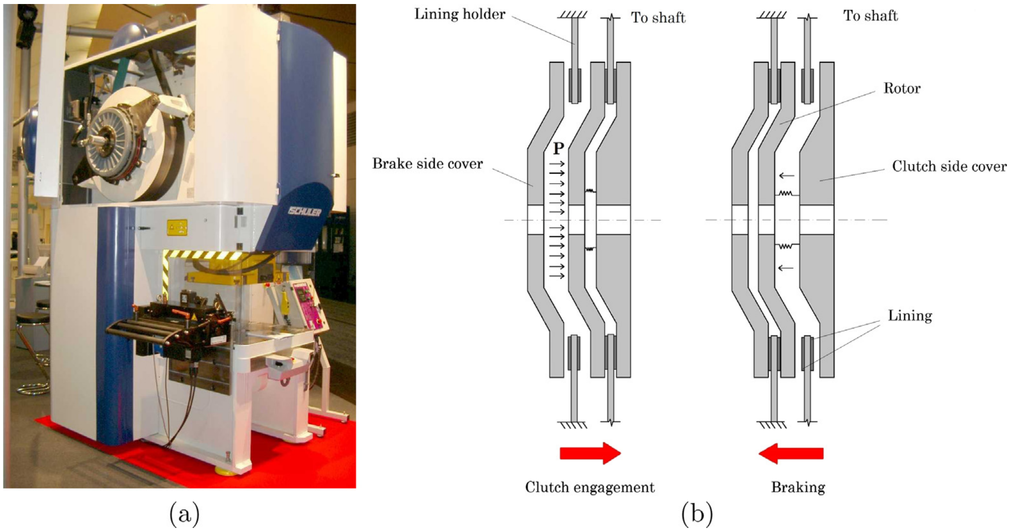


**Fig. 1.** (a) A brake-clutch in a punch-press, its typical application in industry; (b) schematic of the brake-clutch showing its main parts and functioning.

As for clutch models, most papers about clutch noise focused on either low frequency noise [8–10] or thermoelastic effects [11,12]. Regarding high frequency noise (up to a few kHz according to [13]), two models can be highlighted: (i) the 6-DOF squeal model presented in [14] in which mode coupling instability was studied and compared with eek noise measurements in a dry friction clutch and (ii) the 2-DOF nonlinear model of a squealing clutch in [13,15] in which the effect of friction forces and gyroscopic action in mode coupling was analysed. Despite these efforts, according to [16] nowadays there is no industrial model in the literature for studying squeal in clutch systems.

On the subject of squeal suppression, design modifications are the preferred means to achieve this objective. These modifications are mainly based on mode shapes [7,17] and are generally performed following an iterative scheme mostly by trial and error until a suitable solution is found [18]. Recently, optimisation techniques such as shape optimisation have also been applied [19]. The main limitation of this approach is that as the whole system is affected, the elimination of one instability can create another that was not previously present.

Another way to determine a modification for squeal suppression is using the receptance function, which allows to assign both natural frequencies and zeros by the addition of point modifications that can be theoretically computed. Methods based on the receptance function have been successfully applied in other fields to solve the inverse problem of structural modifications on a simple laboratory structure and simple simulated examples [20,21]. Regarding squeal, only the direct problem has been solved this way. This means that the effect of a modification on the squeal frequencies can be predicted but not the needed modification to achieve a certain change in the behaviour of the system. In [22], for instance, experimental receptances were used to compute the effect of the addition of a single-DOF system in a simplified test bench. In a system that presents squeal, being able to shift natural frequencies allows to avoid mode coupling since two modes that are close enough in frequency to coalesce due to friction can be taken apart from each other. This makes the receptance method a possible strategy for squeal suppression. In addition, as the needed modifications are local, the design of the system is not compromised. The main drawback of the method is obtaining accurate experimental receptances from the system but if a reliable finite element model is first developed, simulation receptances can be used as they can include the effect of friction [23]. The need of a model as close to the real system as possible renders the simplified models previously described ineffective for squeal suppression based on receptances.

Therefore, the aim of this work is to establish a methodology for brake-clutch squeal suppression by either mass or stiffness point modifications based on simulation receptances. This methodology will be applied in a simplified laboratory brake-clutch structure.

The paper is organised as follows: first, the brake-clutch squeal model developed is described; then, squeal tests are performed and the numerical model is validated; then, the receptance method is used to propose a point structural modification for squeal suppression and the results obtained are applied.

## 2. Description of the simple model of the brake-clutch

The model used has three distinct features [24]:

- *Simple geometry* of the theoretical model to avoid unnecessary details.
- *Experiments conducted on a commercial tribometer* because of its integrated sensors and control for rotating speed and pressure.