ON THE CONTROL OF FRICTION INDUCED VIBRTIONS THROUGH AN ADDITIONAL SEQUENTIAL FRICTION-SPRING

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Summary This contribution investigates a new way to control the vibration amplitudes of friction induced vibrations. The classical friction slider system is modified by an additional sequential spring supplied with an additional dry friction element. It is shown that it is possible to control the amplitude of the friction induced limit cycle and even to supress it completely by adjusting the level of this additional friction. Two types of additional friction are considered: the conventional one and friction proportional to the deformation of the spring. Analytic predictions are obtained for the stationary limit cycle and compared to numeric simulations. The structure of the phase space with two additional limit cycles (stable and unstable) is compared with that of the classic system and used in order to generate an effective control. Finally a way to adapt the system to changes in the friction characteristics of the exciting friction element by means of a control-loop is demonstrated.

INTRODUCTION

Friction is one of the most complex phenomena in mechanics. Strongly simplified models of friction are usually used to model the macroscopic dynamics. However they take at least two main effects into account: The first one is the possibility of sticking, i.e. the ability of a friction contact to resist against an applied external force without any macroscopic motion between the contact partners. The second one is the strong dependency of the friction force while sliding from the relative tangential velocity. The great majority of the dry friction interfaces exhibit a negative slope of the force-velocity curve at low slip. This negative slope eventually produces a negative effective damping and may thus cause instability as pointed already by Lord Rayleigh [1]. Another type of instability in systems with dry friction is flutter [2], which is not related to a negative slope of the friction characteristic. The classical example for analysing self-excited vibrations due to negative friction gradient is the friction slider depicted in Figure 1.

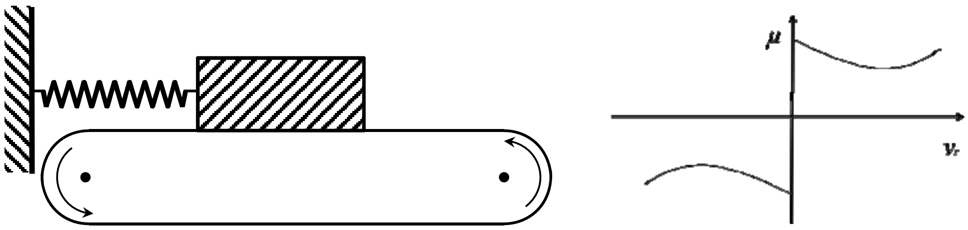

Fig.1. Classical friction slider and the corresponding friction characteristic with negative slope at low sliding speed

Its properties are broadly discussed in literature (cf. [3, 4] for example). However, up to the authors' knowledge, the influences of additional dry friction in the spring and the possibilities to use it in order to control the self-excited vibrations have not been investigated thoroughly in the past. The simplest case of a dry friction element acting parallel to the spring was discussed in a simplified way by Tondl [5] and recently by Hetzler [6].
This paper discusses the possibility to control the amplitudes of self-excited vibrations by means of a sequential friction-spring element.

PASSIV FRICTION SLIDER WITH AN ADDICTIONAL SEQUENTIAL FRICTION-SPRING

The basic structure of the slider with an additional sequential friction damper is shown in Fig. 2 left-hand side.

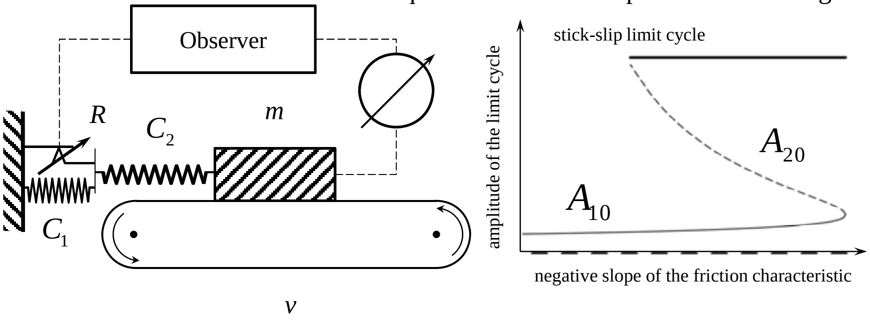

Fig.2. Friction slider with the additional sequential friction-spring and the corresponding bifurcation diagram

As long as the vibration amplitude is sufficiently small, only the main spring C_2 is active – the additional spring C_1 (which can be much stiffer than the main spring) is blocked by the sticking friction element R and doesn't participate in

the system's dynamics. As soon as the vibration amplitude overcomes the threshold of sticking the friction in the additional element provides a significant amount of damping and limits the vibration amplitudes.
Two types of additional friction have been investigated: the ordinary dry friction and the dry friction proportional to the elastic force in the additional spring C_1 (cf. Fig. 3).

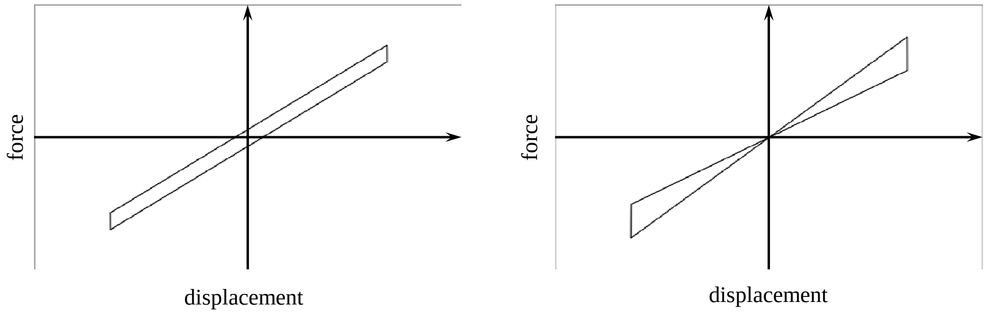

Fig.3. Force characteristics of the additional friction-spring elements

Analytic predictions are obtained for the slow evolution of the vibration amplitude based on discontinuous averaging [4]. The governing equation for the system with classic friction (Fig. 3, left hand side) and the corresponding stationary amplitudes are as follows:

$$A_0' = G_0 A - \frac{2R_0}{\pi}\left(1 - \frac{R_0}{A_0}\right);\ A_{10} = \frac{R_0}{\pi G_0}\left(1 - \sqrt{1 - 2\pi G_0}\right);\ A_{20} = \frac{R_0}{\pi G_0}\left(1 + \sqrt{1 - 2\pi G_0}\right). \quad (1)$$

Here A_0 is the amplitude of the limit cycle; G_0 is the absolute value of the negative slope of the friction characteristic in the main contact and R_0 is the level of the additional friction in the damper element. Index zero stays for non-dimensional variables and parameters. The corresponding bifurcations diagram is shown in the Fig. 2 on the right-hand side. Adding the friction damper does not affect the stability of the equilibrium. Instead a new stable limit cycle with very small amplitude A_{10} appears around this equilibrium alongside with the unstable limit cycle with larger amplitude A_{20} (fold bifurcation). The second limit cycle determines the attraction area of the first one. Trajectories starting outside of this area end in the stick-slip limit cycle with very large amplitudes. A similar analysis has been performed for the second type of the additional friction.

ADAPTIVE CONTROL COMPENSATING THE UNCERTAINTY OF FRICTION CHARACTERISTICS

The described approach allows reducing the magnitude order of the vibration amplitude of the friction slider if the slope of the friction characteristic is known. However in many cases this slope varies due to unpredictable external influences like air humidity, wear or very slow evolution of the topography of friction surfaces. Thus an adaptive control system is necessary in order to ensure optimal performance under all circumstances. The proposed system is based either on a stationary observer estimating parameters of the friction characteristic based on the measurements of the stationary amplitude, or on a non-stationary observer analysing the intermediate dynamics of the slider. In both cases the normal force can then be adapted in order to optimize the system's performance for the actual characteristics of the main destabilizing friction. The comparison between these types of the observers has been performed numerically.

CONCLUSIONS

Vibrations excited in the friction slider due to negative friction gradient are investigated. It is shown that the additional sequential friction-spring element can be used in order to control the limit cycle and enables a tremendous reduction of the stationary amplitudes. Two types of dynamic observers can be used to estimate the parameters of the friction characteristics and adopt the controller's performance to varying external conditions.

References

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