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Young Ju Ahn

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Relaxation damping and friction

Young Ju Ahn[a]

[a]*Department of Mechanical and Design Engineering, Hongik University, Sejong-si, 339-701, Republic of Korea*

Abstract

Recent research has shown that energy losses named as 'relaxation damping' can occur even with an infinite coefficient of friction using the method of dimensional reduction (MDR) which is strictly applicable to axis-symmetric elastic contact problems. If the solution with infinite coefficient of friction is regarded as a limiting case of 'very large' friction, this limiting solution is often useful because it will typically be much simpler than that obtained assuming a finite coefficient of friction, and it is likely to give reasonable estimates for the actual dissipation in cases that are far from the gross slip (sliding) limit. Using the advantage of relaxation damping, we shall give a generalized proof that is independent of the MDR. We shall also extend the proof to problems in which the applied loads follow a general trajectory in three-dimensional vector space. Further, we shall demonstrate how the energy dissipation per cycle varies with an increasing normal force, showing that relaxation damping could be useful as a limit in cases where there is significant variation in a normal force.

Keywords: periodic loading; frictional dissipation; damping

1. Introduction

In a recent paper Popov *et al.* [1] have shown that energy losses can occur in elastic contact problems even with an infinite coefficient of friction, where no slip is possible. They refer to this phenomenon as 'relaxation damping' and liken it to Landau damping in a collisionless plasma.

There exist other examples of elastic contact problems involving dissipation with no slip. For example, Johnson [2] presents the elementary rolling contact problem shown in Figure 1, in which an elastic belt transmits power between two identical pulleys of radius R.

If the tension in the upper belt segment is denoted by T_1 and that in the lower segment by T_2, it is clear that both the driving and driven pulleys transmit the same torque $M = (T_1 - T_2)R$, but their rotational speeds Ω_1, Ω_2 will generally differ because of the extensional strain in the belt. For a finite coefficient of friction f, Johnson shows that a slip arc occurs on the downstream side of each pulley, with angle θ given by the 'capstan' formula

$$T_2 = T_1 \exp(-f\theta) , \tag{1}$$

and the energy loss associated with the difference of rotational speeds can be shown to be exactly equal to the losses due to frictional slip in these arcs. However, the ratio between the rotational

*Corresponding author, yjahn70@hongik.ac.kr