A MECHANISM FOR ENERGY TRANSFER
IN MECHANICAL SYSTEMS

Donald Bedford and Peter Krumm

School of Pure and Applied Physics
University of Natal
Durban 4041, South Africa
E-mail:bedford@scifs1.und.ac.za

Received 10 August 2000; revised 19 October 2000

We propose a general mechanism for the transfer of energy within and
between mechanical systems. The proposal is borne out by the analyt-
cial solution of a model system.

Key words: Poynting vector, energy transfer, mechanical systems.

1. THE PROBLEM

The mechanism of energy transport within and between mechanical
systems in classical dynamics is, on the face of it, obscure. For ex-
ample, what form does the (mass-)energy take as it flows from one
system to another? Some authors have suggested that the 'energy cur-
rent' associated, for example, with work being done by a moving taut
rope, cannot be absolutely located in space, nor can a unique veloc-
ity be assigned to it in any one frame [1,2]. (Note that the energy
flow is in the opposite direction to the motion of the rope.) We argue
here that energy flow in mechanical systems can indeed be absolutely
located and has a unique velocity because energy transport in mechan-
ic systems takes place via the covariant electromagnetic momentum
associated with the necessary, discrete, electrical sub-structure forming
any normal material system.

The forces involved are definitely associated with and localised
within the material substance of the moving rope and it is natural to
suppose that the energy flow is similarly confined to the material of
the rope [1,2]. It is not. It is localisable, in the sense that the fields are
local entities, and there is a well defined energy density at every point
2. THE MODEL

Suppose one end of a taut rope is being wrapped onto a motorised winch, and the other is unwrapping from a drum attached to a brake which causes the brake to heat up (Fig. 1). Energy is thus transferred from motor to brake. It is legitimate to ask what form the energy takes as it passes through a plane perpendicular to the rope midway between the motor and brake. We model this rope by a long, straight line of equal point charges, \( Q \), alternating in sign, separation distance \( s \) (Fig. 2). (Our concern here is with ordinary matter, wherein structural forces are basically electrical, and a model using Coulomb forces is appropriate. It is interesting that a model consisting of gravitating mass points would also work; there is a gravitational analogue of the magnetic field and hence, of the Poynting vector [3]. Indeed, it is easy to show [4] from Relativity that for any force there is an analogue of the magnetic field, and hence a Poynting vector.) We admit that such a system would be highly unstable, but this does not detract from its relevance as an example of a mechanical system that could, in principle, transfer energy from a motor to a brake.

The charges are moving to the right with speed \( v \ll c \). The tension \( T \) in the rope modeled by this line of charge is then given by the force exerted on one of the charges by all the charges to the right of it:

\[
T = \frac{Q^2}{4\pi\varepsilon_0} \sum_{n=1}^{\infty} \frac{(-1)^{n-1}}{(ns)^2} = \frac{Q^2}{4\pi\varepsilon_0 s^2} \sum_{n=1}^{\infty} \frac{(-1)^{n-1}}{n^2} = \frac{Q^2}{4\pi\varepsilon_0 s^2} \cdot \frac{\pi^2}{12}. \tag{1}
\]