Drum- and -Disc-Engine with Shape Memory Wires

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Abstract

A new design is proposed for thermomechanical energy conversion by use of shape memory wires. A prototype of this new heat engine has been built; it converts low-temperature heat into rotative motion and mechanical work.

1. Introduction

Most heat engines make use of the liquid-vapour phase transition, because the addition and withdrawal of the latent heat creates big changes in volume which may be used to produce work. The change of length of wires may in principle be used for the same purpose. However, for a long time such length changes had to rely on the minimal thermal extension of wires and not much work could be produced in that way.

This has changed with the advent of shape memory materials, in which a martensitic austenitic phase transition creates strains up to 10%. While this is still small compared to the 20.000 % volume change of liquids upon evaporation, the forces exerted by the solids are considerable. Therefore, from their beginning, shape memory alloys have been used to construct heat engines, e.g. see [1]. Sofar, however, nothing much more than toys have been built. In the present paper we present details of a prototype engine that produces a torque of 15 Nm and revolves with 20 rev/min.

* Upon presentation at MECAMAT 95 this paper was accompanied by a video film which shows the engine working.

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2. Constitutive properties and two Banks engines

It is customary to represent the constitutive properties as isotherms in load-deformation diagrams or as isobars in a deformation-temperature diagram, see Fig. 2.1 top and bottom respectively.

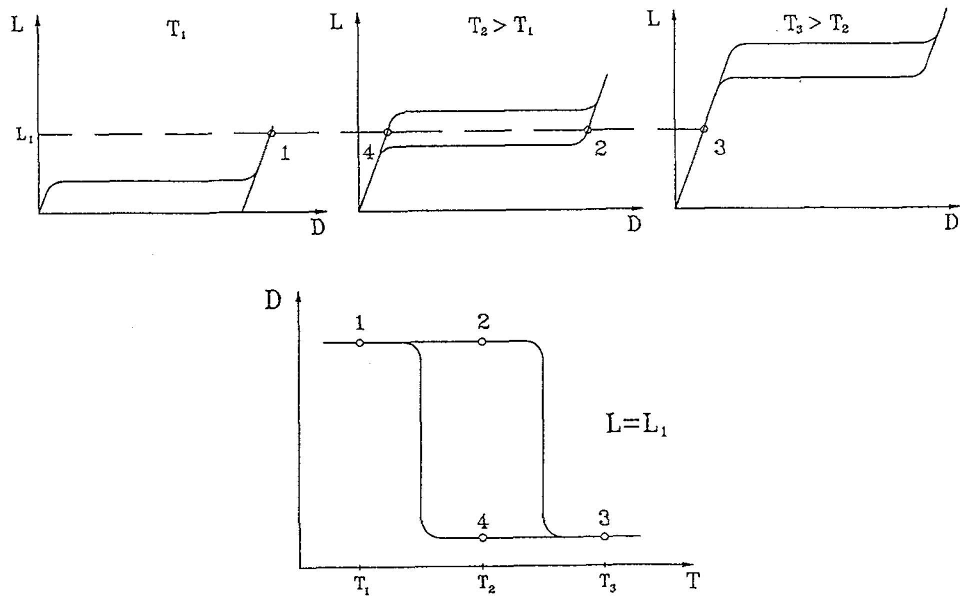

Fig. 2.1 Isotherms and isobars (schematic)

An obvious conclusion may be drawn from the isobar in Fig. 2.1: under a fixed load the deformation changes from large to small and back to large when the temperature is „cycled“, i.e. when the temperature is raised and lowered. Thus a periodic motion may be caused by a cyclic temperature change; and, if the proper gears and cranks are attached, we thus obtain a heat engine.

Most people have seen and admired the ingenious engines built by R. Banks (see [2]) which have often been rebuilt. Fig. 2.2 shows pictures of the rotative Banks engine and of Banks' pendulum machine; both were rebuilt in our laboratory. These engines are no more than toys and, while it is conceivable that they could be enlarged to produce significant power, it is unlikely that the same design would be used. For one thing, the Banks engines - using bent wires, i.e. inhomogeneous deformation - do not press the full mass of the memory material into service; also such bent wires are prone to fatigue. Our own machine avoids these disadvantages by making use of uniaxial extension and contraction of wires.

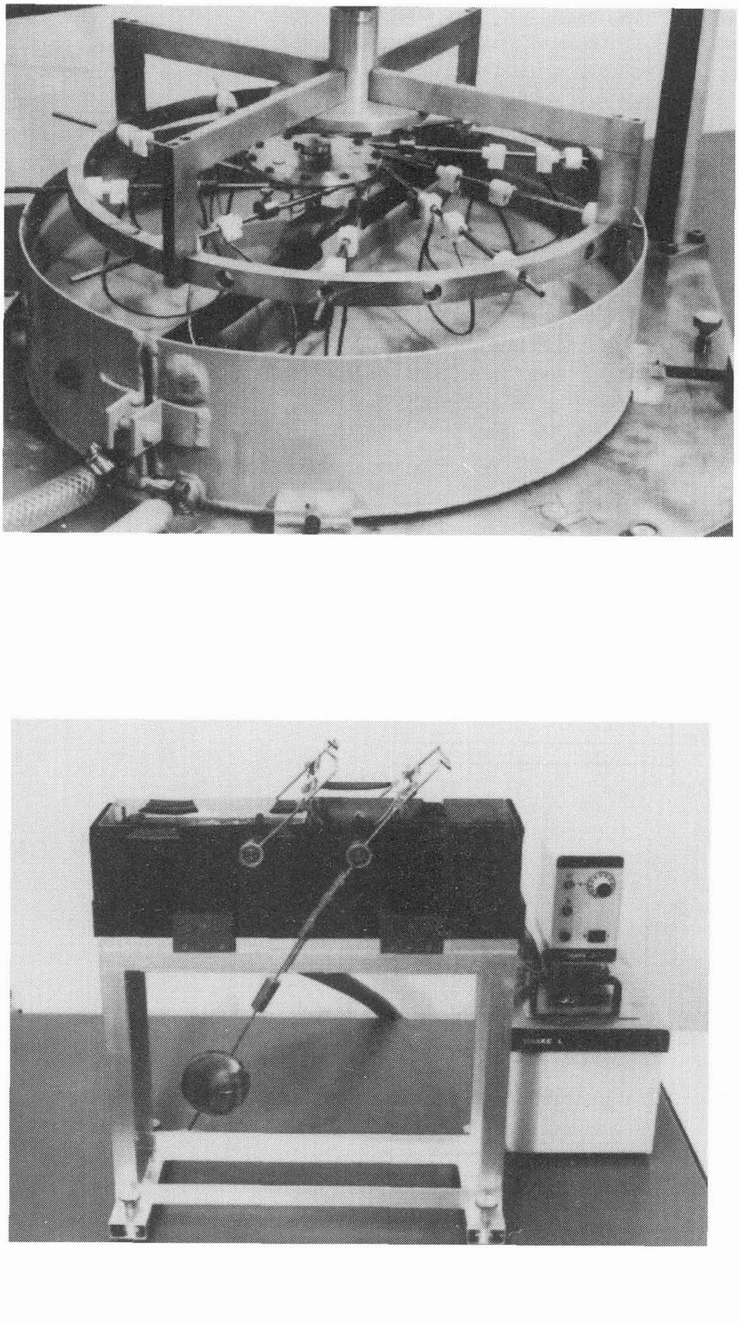

Fig. 2.2 The rotative Banks engine and Bank's pendulum machine

3. The drum- and -disc engine

Our engine is called the drum- and -disc engine, because the working wires are spanned along the mantle lines of a cylindrical drum and they exert a torque on an oblique disc, see Fig. 3.1. The wires are fixed to a flange on the drum on the LHS, and on the RHS they are fixed to the oblique disc. The front part of the drum and its wires are showered by warm oil (85°C) and the back part by cold oil (25°C). The hot wires tend to contract strongly to the small length between the flange and the lowest point of the disc. Thus all wires on the warm side pull on the disc and *the* component of the contracting force, which is tangential to the circumference of the disc exerts a torque and sets the disc into rotative motion. On the disc's inside we have a conical cog-weel which grips into a cog-wheel on the drum at the point of contact, i.e. the bottom point. Thus the rotation of the disc is transmitted to the drum so that the wires are transported along - from warm to cold and back - and so that the power generated can be taken off from the shaft on the LHS. On the lower back side the fully contracted - and unloaded - wires are cold, hence soft, and the motion of drum and disc extends them easily until they reach their maximum length in the uppermost point.

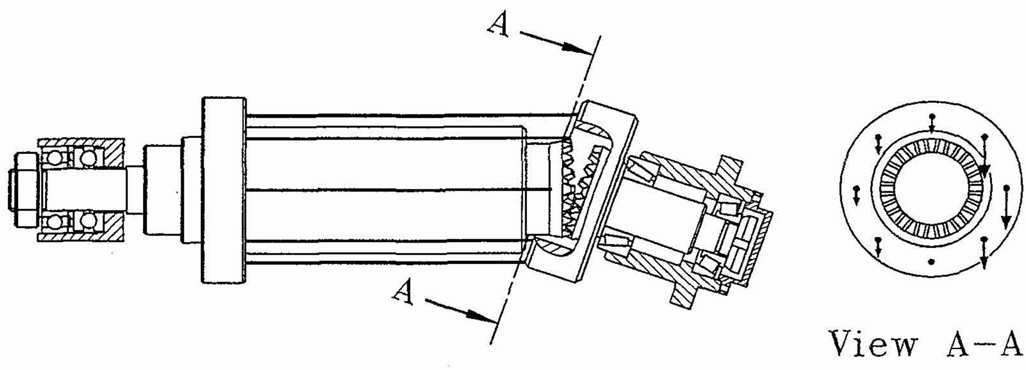

Fig. 3.1 Schematic sketch of drum and oblique disc. View A-A: Forces on the disc. (Shaded parts are non-moving)

In actual reality the construction is a little more complicated than indicated in Fig. 3.1. Fig. 3.2 gives a more detailed picture. In particular there are steel springs that keep the slack out of the wires when the engine is cold, i.e. before it starts. Also Fig. 3.2. shows some details of the mounting of drum and disc. Glasauer [3] has described the engine in detail in his dissertation.

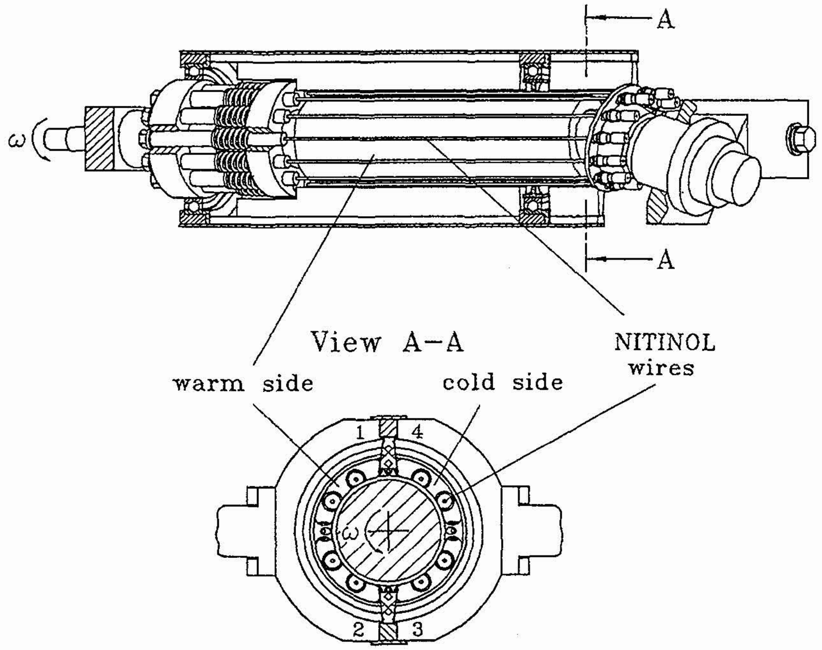

Fig. 3.2 More detailed view of drum- and -disc engine

The wires are 1,3 mm ∅ wires of NiTi from North West High Tech Company in Xi'an, Shaanxi , PR China. The length of the wires is 40 cm and their elongation equals 2,4 cm. The maximum strain of the wires is dictated by the inclination of the disc which is our machine is 19° implying a strain of 6,0 % and there are 24 wires on the drum. The maximum load in each wire is 400 N and the torque on the shaft equals 15 Nm. The biggest number of revolutions sofar achieved was 20 rev/min.

Fig. 3.3 through 3.5 show the engine as a whole and two close-ups of the flange side and the disc side respectively.

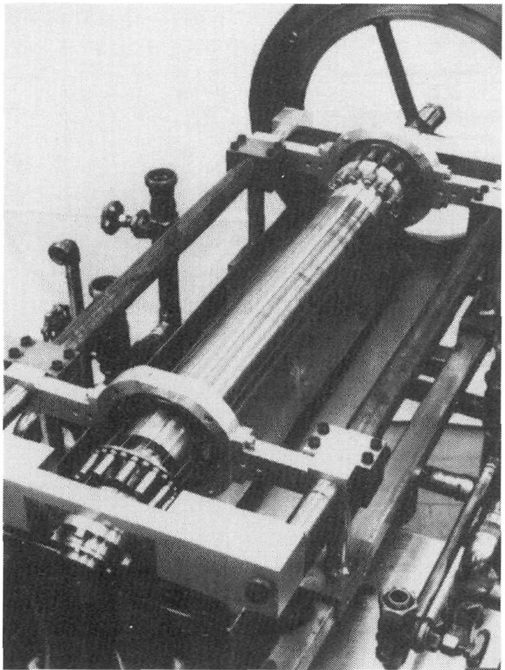

Fig. 3.3: Engine as whole

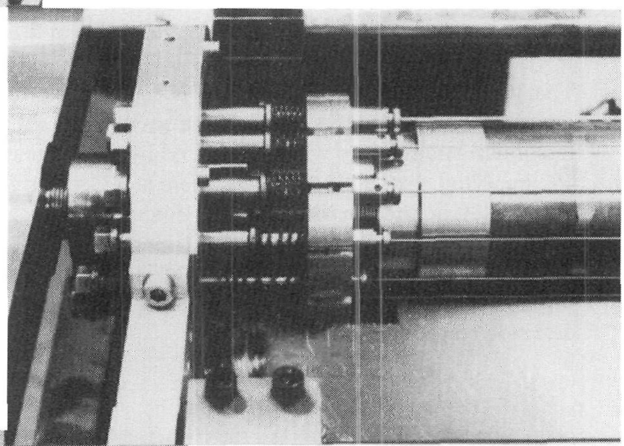

Fig 3.4: Detail on flange side

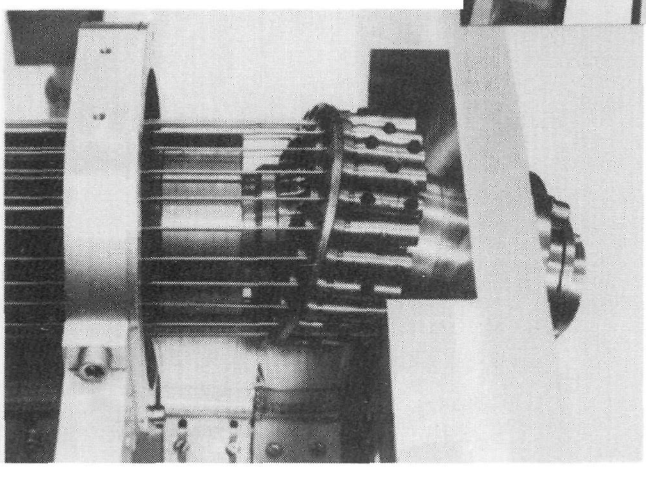

Fig. 3.5 Detail on disc side

4. The thermodynamic cycle

As was described above the wires alternate between a low temperature $T_1 = 300$ K and a high temperature $T_2 = 360$ K, the temperatures of the oil showers on the front and back sides of the drum. The relevant (L,D)-isotherms are taken from Fig. 2.1 and drawn into the single (L,D)-diagram of Fig. 4.1. For simplicity we assume that heating and cooling is instantaneous. Thus heating occurs at the single deformation D_{max} and it brings the wires from the low temperature isotherm in point 4 vertically up to the high temperature isotherm in point 1. The cooling occurs in the origin which is a common point of both isotherms, 2 and 3 respectively.

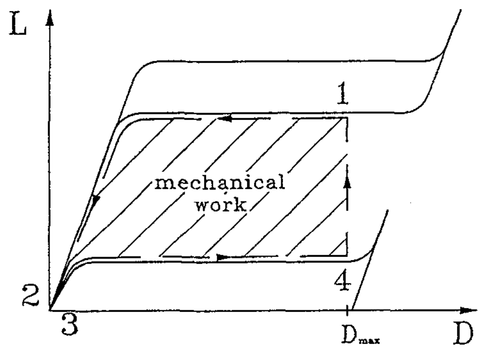

Fig. 4.1 Schematic cycle of drum- and -disc engine

On the cold side the wires are easily extended. It takes no more than 50 N to extend each wire along the yield plateau. On the warm side the wires contract with a force of 400 N along the recovery plateau. The work done by each wire in a cycle is represented in Fig. 4.1 by the shaded area inside the process curve of the cycle. With the numbers given the value of that work is approximately 8.4 J.

References

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[2] Banks, R., The Banks Engine: Past, Present, Future, NSWC-MP-79-441 (1978).
[3] Glasauer, F.-U., Dissertation TU Berlin (in preparation).