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G. W. Gatecliff

H. S. Henry

SIMULATION OF THE DYNAMIC PERFORMANCE OF A VARIABLE WIDTH CANTILEVER SUCTION VALVE USING COMPUTER GRAPHICS

G. W. Gatecliff, Chief Research Engineer
H. S. Henry, Mechanical Engineer
Tecumseh Products Research Laboratory, Ann Arbor, Michigan

ABSTRACT

The results of a mathematical analysis of the forced vibration of a variable width cantilever leaf valve are presented. The time-dependent behavior of the valve is simulated with the aid of computer-generated images displayed in rapid sucession on a cathode ray tube. A sequence of photographs illustrating the highlights of one such animation is included.

INTRODUCTION

Automatic reed valves are commonly used in hermetic compressors. They are found in many geometric configurations and are intended to function in such a way that the working fluid passes in a single direction through an associated port. Actual behavior is a function of fluid forces acting externally, flexural forces developed internally, constraints limiting the motion and the mounting arrangement.

Numerous analyses of the forced vibration of flapper valves have been undertaken in the past. Early work in this area assumed the leafs to be cantilever beams of uniform width (1,2). Subsequent studies dealt with non-uniform cross sections and practically significant stop configurations (3,4).

Work of this type is highly mathematical in nature. The results are often voluminous and difficult to visualize in tabular form. Graphical techniques offer a way to overcome this obstacle to understanding. A case study utilizing this approach is presented here.

A cantilever leaf valve is commonly analyzed as a non-uniform bar in transverse vibration. The cross-sectional dimensions of the valve are commonly assumed to be small in comparison with its length. Fluid forces acting on the reed are considered to be point loads applied at the ports. The beam equation describing the behavior of the valve assumes the following form as the result of these idealizations.

$$\frac{\partial^2}{\partial x^2}\left[EI(x)\,\frac{\partial^2 y(x,t)}{\partial x^2}\right] + m(x)\,\frac{\partial^2 y(x,t)}{\partial t^2} = F_j(t)\,\delta(x-x_j)$$

A typical suction valve has two sets of boundary conditions. The first pertains to a clamped-free beam and applies when the valve is neither in contact with its seat nor stop (see Figure 1).

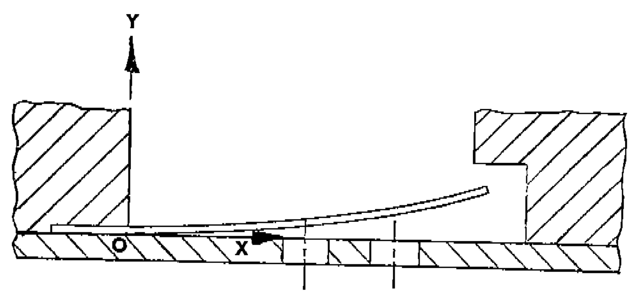


Figure 1

Clamped free:

$$y(0,t) = 0 \qquad \frac{\partial y(0,t)}{\partial x} = 0$$

$$\frac{\partial^2 y(L,t)}{\partial x^2} = 0 \qquad \frac{\partial^3 y(L,t)}{\partial x^3} = 0$$

The second defines a clamped-pinned beam and describes a valve in contact with a tip stop (see Figure 2).

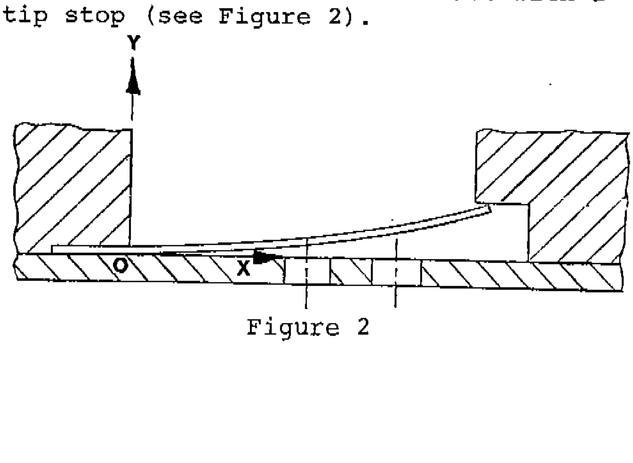


Figure 2

Clamped-pinned:

$$y(0,t) = 0 \qquad \frac{\partial y(0,t)}{\partial x} = 0$$

$$\frac{\partial^2 y(L,t)}{\partial x^2} = 0 \qquad \frac{\partial^3 y(L,t)}{\partial x^3} = 0$$

The approach discussed in Reference 3 was employed to produce the results presented here. A short-form outline of this technique may also be found in Reference 5. The reader wishing this type of information is referred to these works where the subject is dealt with in its entirety.

This procedure has the effect of lumping the mass into discrete elements distributed along the length of the beam as shown below:

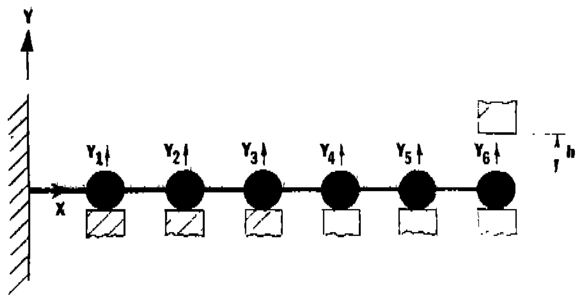


Figure 3

The constraints shown in Figure 3 are those imposed by the valve plate and the tip stop. These restrictions place the following mathematical limitations on the motion of the valve:

M_1: $0 \leq y_1$

M_2: $0 \leq y_2$

M_3: $0 \leq y_3$

M_4: $0 \leq y_4$

M_5: $0 \leq y_5$

M_6: $0 \leq y_5 \leq h$

A bounce type of analysis is employed whenever a violation of the position constraints is encountered.

The suction valve pictured in Figure 4 is the subject of this study.

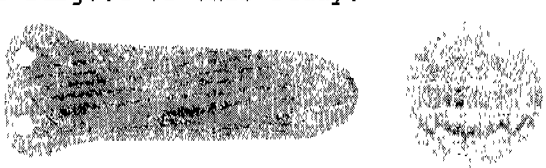


Figure 4

Figure 5 illustrates the limitations placed on the motion of the valve tip. The lower restriction is due to the valve plate and acts along the entire length of the valve. The upper limit is imposed by a tip stop designed to limit the motion of the valve.

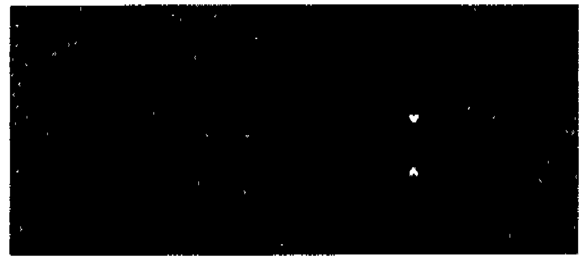


Figure 5

Each of the photographs labeled as Figures 6-31 is a separate position selected from an animation of the valve's motion. The pictures show motion of the valve during one revolution of the crankshaft. Each picture was produced by photographing the screen of a CRT terminal driven by a digital computer.

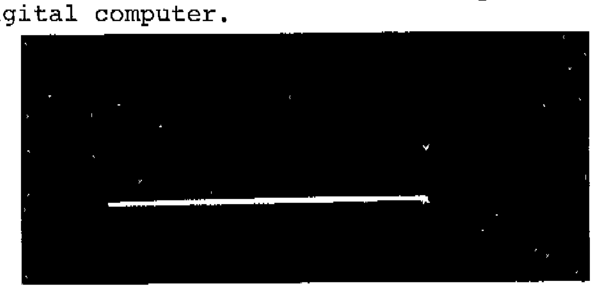
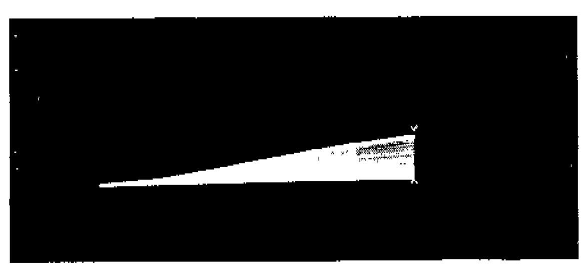


Figure 6

Figure 7



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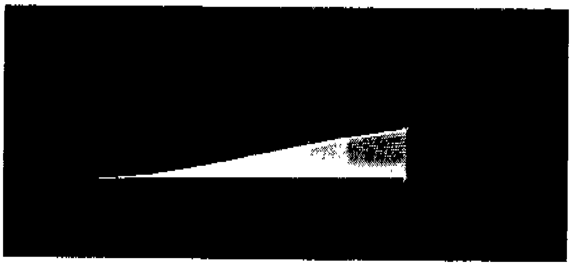


Figure 9

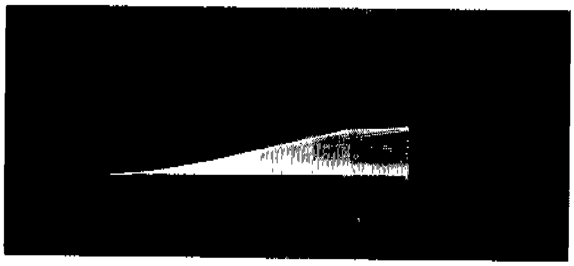


Figure 10

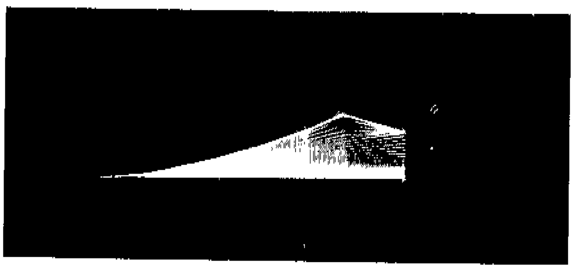


Figure 11

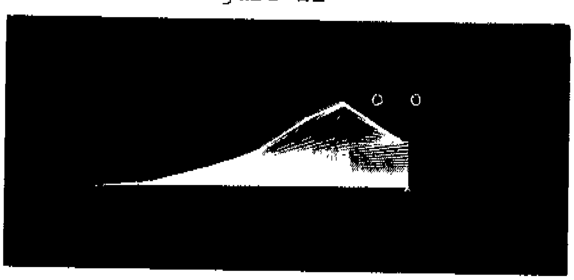


Figure 12

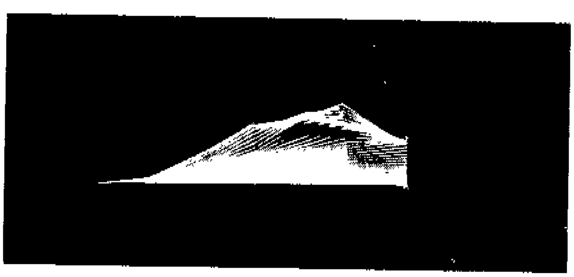


Figure 13

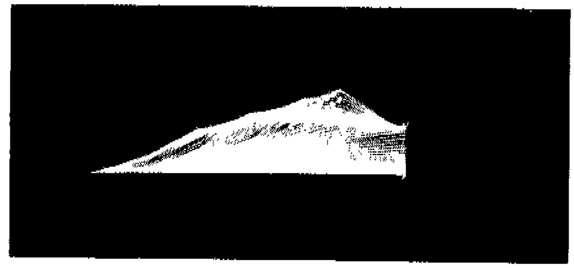


Figure 14

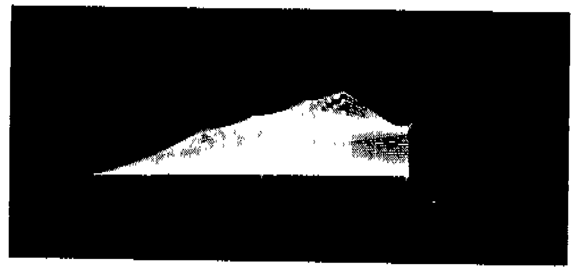


Figure 15

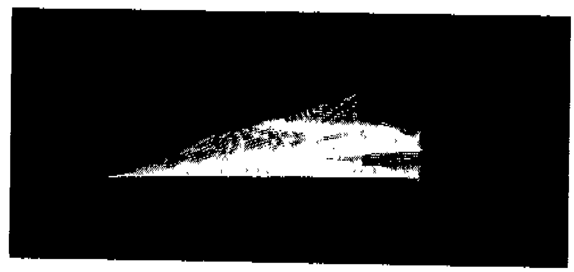


Figure 16

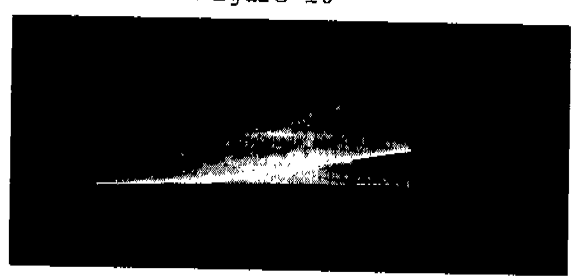


Figure 17

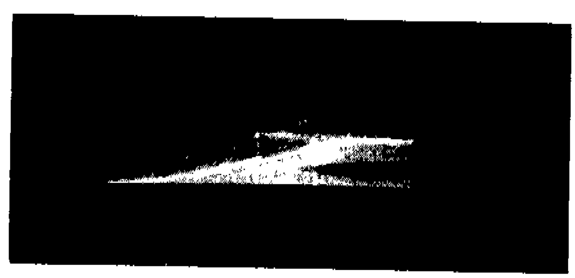


Figure 18

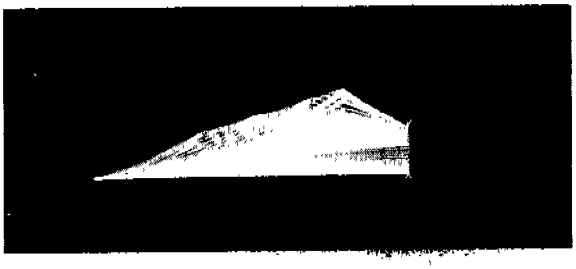


Figure 19

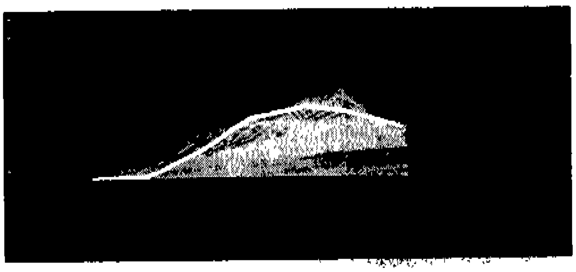


Figure 20

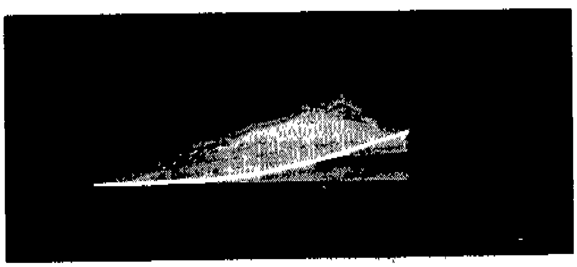
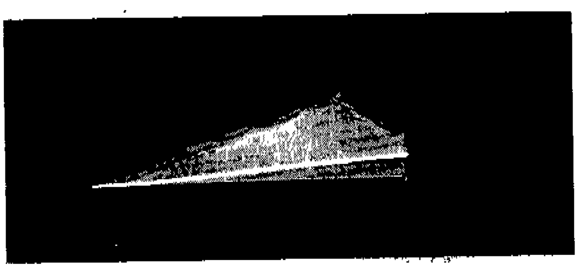


Figure 21



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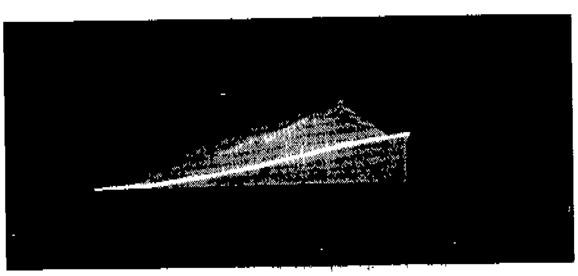

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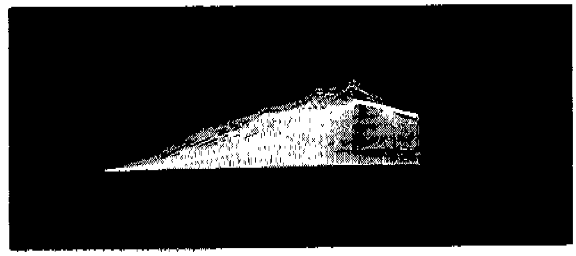

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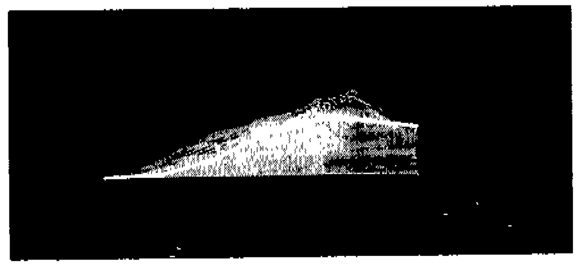

Figure 25

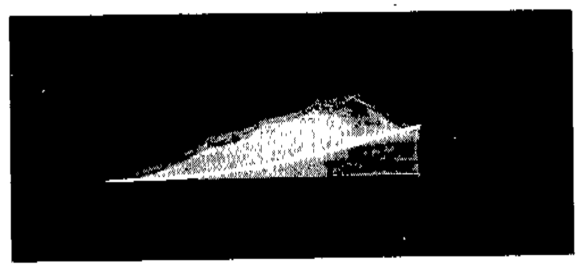

Figure 26

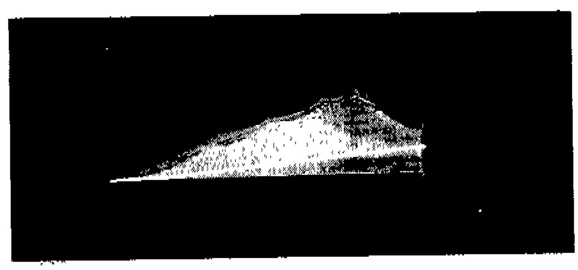

Figure 27

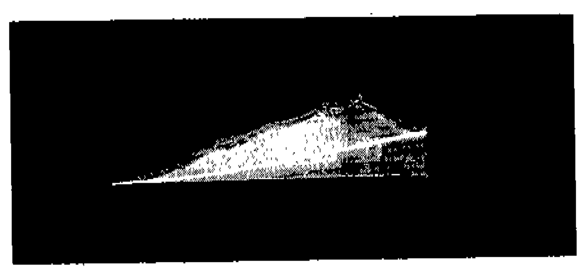

Figure 28

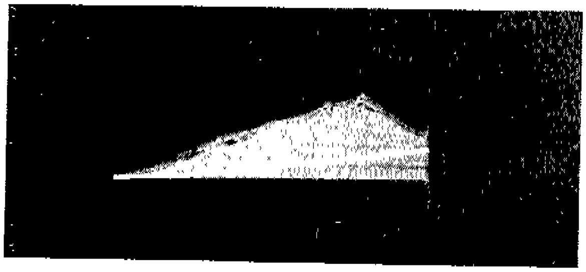

Figure 29

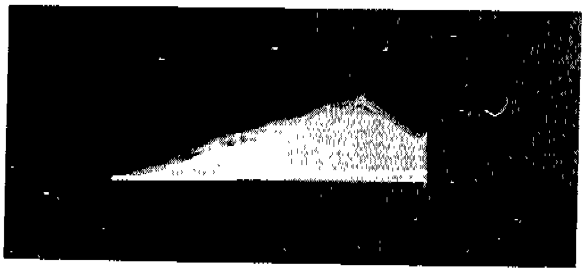

Figure 30

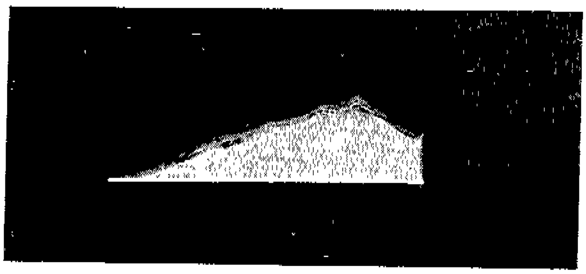

Figure 31

The simulation predicts three impacts between the valve and the stop during each revolution of the crankshaft. The first two interactions with the stop produce a noticeable amount of "overshoot" or "reverse bending" in the body of the valve. The third interaction is much less violent.

Figures 10-15 illustrate successive positions of the traveling displacement wave generated during the first collison of the valve and stop. Figures 18-21 illustrate an identical sequence of events arising out of the second impact with the stop. The resulting waves travel along the length of the valve similar to those in a "plucked string" held taut.

CONCLUDING REMARKS

The procedure illustrated here is a generalized technique that can be applied to a valve of any shape that can be described mathematically. The use of computer graphics as an output medium provides an immediate feel for the calculated solution and the insight it offers.

LIST OF SYMBOLS

$(x-x_j)$ - Kronecker delta equation; defined as 0 for $x \neq x_j$, equal to 1 for $x = x_j$

E - Modulus of elasticity

F_j - Amplitude of force at distance x_j from base of valve

$I(x)$ - Area moment of inertia about the neutral axis

$m(x)$ - Mass per unit length

t - Time

x - Distance from base of valve

x_j - Distance from base of valve to force F_j

y - Valve deflection

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