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Cronhjort, A.

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A COMPUTER-CONTROLLED BOWING MACHINE (MUMS)*

Andreas Cronhjort

Abstract

MUMS is a bowing machine, i.e., a machine that bows (plays) a violin in a controlled and repeatable manner by mechanical means. Traditionally, the main application of bowing machines has been in studying string vibrations and violins under reproducible conditions. MUMS uses a normal bow to excite the violin, which also allows a comparison of different bows and their influence on the string vibrations. The position and velocity of the bow and the force between bow and string ("bow pressure") can be specified and controlled within close limits. MUMS consists of two parts: a converted printer which contains the mechanical support of the bow and motors for bow motion and force, and a PC-computer which controls the motion by software servos.

INTRODUCTION

It is well-known that the sound quality of a violin is influenced by the particular bow used. The mechanism underlying this interaction between bow and instrument is not known as yet, but it has been assumed to be connected with the normal modes (resonances) of the bow. The resonances of a violin bow include both transversal modes of the bow stick, and longitudinal resonances in the bow hair (Askenfelt, 1992). A modulation of the bow force, as well as a periodic variation in bow velocity during sticking, have been proposed as possible explanations by which the bow modes could interact with the string (Cremer, 1984; Schelleng, 1973).

The aim of this project was to design and build a bowing machine which "plays" the violin with a normal bow. Such a machine would allow a comparison of bows and their influence on the string vibrations under controlled and repeatable bowing conditions. The machine was given the acronym MUMS (MUscerande Maskin för Stråkar).

Bowing parameters

When bowing a violin, three parameters control the string vibrations, and hence, the radiated sound: (1) $v$, the velocity of the bow, (2) $F$, the force between bow and string (bow force or "bow pressure"), and, (3) $x$, the distance from the bridge to the bow (bow-bridge distance). These parameters are defined in Fig. 1.

![Fig. 1. Definition of the bowing parameters $v$, $F$, and $x$.](image)

![Fig. 2. Principal relation between maximum and minimum bow force and bow-bridge distance for a given bow velocity. (Adapted from Schelleng, 1973.)](image)

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The bowing parameters must be kept within certain limits in order to generate a normal violin sound (Schelleng, 1973). The velocity is normally kept between 40 mm/s and 3 m/s, and the bow force between 0.1 and 3 N. The bow-bridge distance is typically between 10 and 60 mm (Askenfelt, 1986; 1989). The shorter the bow-bridge distance, the narrower is the allowed range in bow force (see Fig. 2).

In order to limit the project to a reasonable amount of work, it was decided to let the bowing machine control the bow velocity and bow force, while the bow-bridge distance was set manually.

Fig. 3. A bowing machine using a rotating loop of bow hair to excite the string.

Earlier bowing machines

In the past, researchers have tried several methods of bowing violins in a mechanical manner (Saunders, 1937; Bradley, 1970; Coates, Higgs, Parsons, & Townsend, 1975; Barnes, et al., 1983). As they primarily were interested in the properties of the violin, they usually not used a real bow for the excitation of the string.
Instead, the bow hair was mounted on some simpler moving or rotating device in order to make the instrument sound. One popular way of machine bowing has been to mount a loop of bow hair between two wheels as shown in Fig. 3. Another solution has been to use rotating discs of celluloid which were treated with rosin, see Fig. 4. A few bowing machines used a real bow to excite the string like the one in Fig. 5 (Raman, 1920; Lawergren, 1980).

The old bowing machines could only be used for taking measurements under steady-state conditions, often by measuring the radiated sound ("response curves"). Recently, a simulation of the bow by means of an electrodynamic system controlled by software has proven successful in exciting the string in a bowing-like manner, "the digital bow" (Weinreich & Caussé, 1986).

Fig. 4. A bowing machine using a rotating disc to excite the string (Saunders, 1937).

Fig. 5. A bowing machine using a normal bow to excite the string (Raman, 1920). Notice that the bow is fixed while the violin is moved by the mechanics.
DESCRIPTION OF MUMS

Mechanical design

The outline of the bowing machine MUMS is shown in Fig. 6 (a). The main part of
the machine consists of a surplus printwheel printer, interfaced with a PC-computer.
The violin is mounted in a fixed position at the side of the machine.

![Diagram showing MUMS overview and mounting of bow to carriage](image)

Fig. 6.  (a) Overview of MUMS.  (b) Mounting of bow to carriage

The bow is clamped to a carriage (formerly carrying the print wheel) which can
move along a rail guided by linear roller bearings. The carriage is pulled by the
original (powerful) DC-motor via a belt. The maximum stroke is about 330 mm. The
bow position and velocity are controlled by a software servo, with the position feed-
back read optically on the shaft of the carriage motor. The maximum velocity is 1
m/s approximately.

The bow force is controlled by applying a torque to the frog (handle) of the bow.
This is done by pivoting the carriage a little by means of a electrical motor. The bow
is not clamped directly to the carriage but to a somewhat flexible cantilever, which
bends as a torque is applied. The motor that controls the torque (formerly rotating
the print wheel) is mounted on the carriage. The torque is controlled by a second
software servo, which computes the actual bow force at the point of contact with the
string, knowing the position of the bow (and violin). The feedback to the servo is
obtained from strain gauges on the cantilever measuring the bending, and thus indi-
rectly the torque. The maximum torque is approximately 0.6 Nm, corresponding to a
maximum bow force at the tip of a little less than 1 N.

Servos

The servos controlling the bow motion and force are implemented in software.
The position servo is a PID-algorithm which gives excellent performance at normal
bowing velocities, the positioning error being typically less than 1 mm. At transient
events, as for short notes with a sudden onset and termination (sforzando, marcellato),
the error may temporarily be larger (see Fig. 7).

The servo for the bow force is also based on a PID-algorithm, but assisted by a
feed forward loop. Together, this gives acceptable performance at low frequency,
with a force error of typically 10 mN. At higher frequencies the regulation is poorer
and the ringing after a transient could be disturbing. The performance at high fre-
quencies is closely connected with the heavy design of the carriage. The large mass
adds a negative phase angle to the loop gain at higher frequencies. The ringing is
enhanced by the low losses in the cantilever to which the bow is mounted, and in the
bow itself.
Generating data files

Data files specifying the bow motion and force versus time can be generated in two ways; synthetically by algorithms giving well-defined parameter values, or manually by "playing" MUMS by hand, which gives more realistic parameter profiles. The synthetic files can be generated from different types of functions, including constant velocity and force, or cosine profiles. When playing manually, MUMS enters a record mode and bow motion and force are sampled. In this case, the player uses a fixed frog mounted to the carriage to move the bow. Any bowing pattern produced by the experimenter can thus be reproduced as many as times as desired.

![Graph](image)

**Fig. 7. Transient response of the positioning servo for a short note with a sudden onset and termination (martellato): bow position (dashed) and bow velocity (full line). The thin dotted line shows the actual velocity when MUMS reproduced the bow stroke.**

CONCLUSIONS

In its present version, MUMS meets the specifications which were drawn up at the start of the project. A number of experiments on violin bows and bowing can thus now be foreseen, in which MUMS will play a central role. However, some improvements could be of interest to implement in the future.

An alternative (third) way of creating data files would probably be practical. Admittedly, it is a little difficult to create representative data files by bowing
manually, as the movements of the bow are rather restricted by the mechanics of the printer. A possible alternative would be to use the mouse as input and move a virtual bow on the screen. Another solution would be to specify bow motion and force by drawing curves in an interactive graphic environment.

The performance of the bow force servo, in particular the transient response, could be improved by using a motor capable of a higher torque. An extensive use of MUMS will probably give rise also to other improvements.

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REFERENCES


