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CONTROL OF TURNTABLE SPEED TO COMPENSATE FOR DISC ECCENTRICITY

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ABSTRACT

A method of turntable speed control, still under development, is described which is intended to minimise the slow frequency variation ("wow") caused by disc eccentricity. No special transducers are required since the pickup output has a component due to the "wow". This can therefore be used as the error signal in a control loop designed to vary the angular velocity of the platter in order to keep the tangential velocity at the stylus relatively constant.

INTRODUCTION

The human ear and brain is remarkably sensitive to frequency variation whilst being insensitive to absolute frequency. Shower and Biddulph [1] note that for frequencies of approximately 1000 Hz the differential pitch sensitivity is about 0.03%, i.e. 3 Hz in 1000 Hz. For frequencies lower than 1000 Hz the smallest detectable difference remains at about 3 Hz. There are many factors which affect the subjective assessment of frequency, or more usually musical pitch, variation. Some of these are the intensity, the harmonic content and the duration of the sound. These have been the subjects of numerous publications of a psychological nature but in this paper such matters are not addressed since the view is taken that any engineering imperfection in the disc, turntable or its drive system causing "wow" should be minimised in any case.

Most modern turntables and drive systems are machined to a very high accuracy and some even incorporate a control system using optical sensing from stroboscopic markings on the turntable. Discs themselves, however, are subject to machining tolerances in the hole position and diameter. Also early discs, or ones which have had many playings, exhibit eccentricity and/or enlarged holes. The effect is, therefore, to cause the tangential velocity at the playback stylus to vary with a resultant periodic pitch variation. The study being undertaken is, therefore, aimed firstly at sensing the tangential velocity variation and secondly at constructing a control loop to correct for this.

THEORETICAL BACKGROUND

Consider a disc with an off-centre hole (Fig.1) and a stylus tracking at radius r_1. After 180° of disc rotation the effective radius has changed to r_2. For a small angle, θ, the arc length (s) is given by $r_1\theta$ and the tangential velocity (V_T) is :

$$V_T = \frac{ds}{dt} = r_1 \frac{d\theta}{dt} = r_1 \, \omega_p$$

where ω_p is the angular velocity of the platter. If ω_p is considered constant then :

$$V_{T1} = r_1\,\omega_p \text{ and } 180° \text{ later } V_{T2} = r_2\,\omega_p$$

The fractional variation in tangential velocity, and therefore in pitch, is :

$$\Delta = \frac{(V_{T1} - V_{T2})}{(V_{T1} + V_{T2})/2} = \frac{r_1 - r_2}{(r_1 + r_2)/2}$$

Unless the disc is grossly eccentric $(r_1 + r_2)/2 \doteqdot r_1$

$$\therefore \quad \Delta \doteqdot 1 - \frac{r_2}{r_1}$$

At the end of the playing surface of an LP disc the radius is approximately 70mm so to achieve a Δ of 0.3% with r_1 = 70mm then r_2 = 70.2mm. An effective differential radius of 0.2 mm can be caused by an oversize hole due to poor manufacture or wear.

The convention for groove cutting on a stereophonic disc is shown in Fig.2. Monophonic (i.e. laterally cut) disc compatibility is achieved by summing the two channels so any lateral motion caused by eccentricity will manifest itself in the sum whilst disc warp will cause an output in the difference. There will therefore be a component of pickup output at the frequency of rotation of the turntable (0.56 Hz) which may be extracted from the recorded music by summing the channels and filtering.

CONTROL LOOP

The outputs from the magnetic cartridge are buffered then summed to create the laterally sensitive output (see Fig.3). This is then filtered and amplified using a filter with a cut-off frequency of 5 Hz. Outputs from the pre-amplifier stages of a commercial amplifier are not used since they will normally have rumble filters built in. The resulting voltage due to the eccentricity (v_w) will then be summed with a manually adjustable voltage (v_s) to set the speed. This will then form the drive voltage (v_d) to a linear voltage controlled oscillator (VCO) which has a power output stage driving the turntable's synchronous motor.

The basic relationships of the loop are :

$$\text{platter angular velocity } \omega_p = GK_m\,\omega_o$$

where GK_m is the mechanical gear ratio and motor constant relating oscillator angular frequency ω_o to platter angular velocity ω_p.

$$\text{but } \omega_o = K_o v_d$$

where K_o is the slope of the VCO characteristic (rad $sec^{-1}volt^{-1}$) and v_d is the VCO drive voltage.

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$$v_d = v_s + v_w$$

$$\therefore \quad \omega_p = GK_mK_o [v_s + v_w]$$

The angular velocity of the platter therefore becomes a function of the "wow" voltage generated in the cartridge. As the loop proposed has proportional control the "wow" can never be eliminated but with a high system gain the effect should be minimal. The turntable system must have a low inertia in order to be able to follow the demanded speed variation.

PRELIMINARY EXPERIMENTAL RESULTS

Experimental work has been undertaken using a Thorens TD125 MKII turntable which is a belt drive model with a Wein Bridge oscillator and power output stage driving the motor. In this model the heavy outer platter can be removed. An SME model 3009 arm fitted with a Shure M44E cartridge was used to pick up the signal from a disc in which the hole was filed so that it was too large. Buffer amplifiers on each channel then fed summing and differencing amplifiers with a gain of 100 and a low-pass characteristic with a cut-off frequency of 5 Hz. The effect of the "wow" can be seen in the oscilloscope photograph of Fig.4. The upper trace (A + B) clearly shows the envelope caused by the eccentricity, with a period of just less than 2 secs whilst the lower trace (A - B) shows the efect of disc warp causing vertical motion of the stylus. Note this is not in phase with the "wow" and has an envelope of twice the frequency showing the two warps in the disc.

DISCUSSION

Work is continuing on the design of the control loop beginning with an improved filter of low phase distortion and a high roll-off rate. A digital filter would achieve this requirement although an n-path filter using the VCO as a clock may be a more practical realisation as long as the higher orders of the comb response are removed with a conventional filter. It is proposed to use an integrated circuit form of VCO but these commonly have square and triangular outputs so sine shaping will be required to avoid large losses in the motor.

Another form of control loop would be to use a digital filter implemented with a microprocessor. Since the frequency of interest is very low and the "wow" voltage would be in numerical form, there would probably be enough time for the microprocessor to control a stepper motor instead of an analogue motor. This would overcome potential speed errors caused by, for example, VCO temperature drift and make unnecessary the building of the VCO, sine shaper and linear power output stage.

REFERENCES

[1] E.G. Shower and R. Biddulph, Differential pitch sensitivity of the ear. JASA III, 1932, p.275-87.

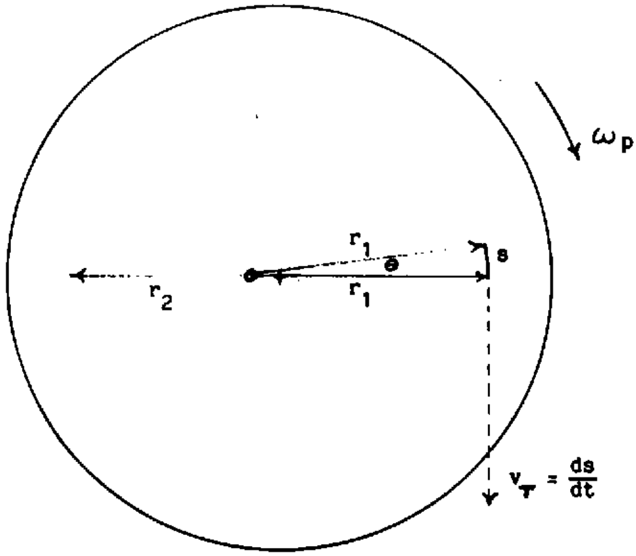

FIGURE 1

Disc radius and velocity relationships

FIGURE 2

Groove cut conventions

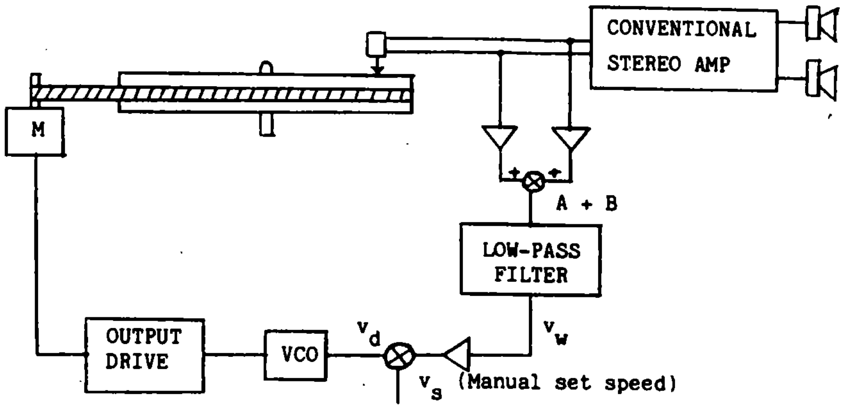

FIGURE 3

Proposed control loop

FIGURE 4

Outputs from low-pass filters for A + B (upper trace) and A - B (lower trace)