cants. But as your guardian in the maintenance of member grade standards and stature, they have no choice but to withhold favorable action if the applicant is not qualified or if he has neglected to comply with the requirements laid down in the bylaws.

In preparing applications, all too frequently the applicant neglects to submit sufficient information to substantiate the experience or other qualifications which he has claimed. It is helpful for an applicant to bear in mind in preparing applications that the Admissions Committee will know only what he submits to them, and must judge his work largely upon the description he he provides. The comments of his references are relied upon to substantiate his claims and not, in general, to add further details. An applicant should recognize that he has an obligation to comply with the bylaws of an organization in which he seeks membership or upgrading, and he should perceive that the processing of his application would be facilitated if he complied as completely as possible.

It would be helpful for applicants, insofar as possible, to select references to verify his entire experience, rather than having all of them selected to verify only the last year or two. This in itself may make it easier to find references, particularly if the applicant has recently transferred to new employment and has not yet established many new acquaintances.

The second main difficulty arises because persons receiving reference forms, for various reasons, do not reply, or do not do so promptly. Frequently, this is found when the person to whom it was referred feels that he does not know the applicant, does not know enough about him, or is reluctant to recommend a denial of the application. In such cases, it is necessary for the headquarters group to follow up the original reference with further correspondence, pointing out that the application remains dormant until the necessary number of references have been heard from.

It is urged that those receiving reference forms return them promptly with their recommendations or, if they prefer not to make recommendations, so to indicate in order that other references may be used or sought. In fairness to the applicant and others involved, those named as references should inform headquarters of their wishes in the matter. Indefinite delay in returning reference forms may prejudice unfairly the ultimate outcome of an application, whereas prompt return with a note that the applicant is unknown or not well enough known will not influence the action taken.

A large proportion of new applications for membership are stimulated by association with IRE members, and many of the applications for transfer are stimulated by the Sections Committee or officers. It is urged that, where possible, members of the Institute should aid new applicants in filling out their forms so as to insure that experience is properly specified, at least the minimum number of qualified references is named, and that the forms are complete and properly addressed. In so doing you can be of great assistance in eliminating a duplication of work and much loss of time, and you will also help prevent loss of membership on the part of applicants who become irritated or discouraged by extended correspondence, requests for more names, and the like. And it is urged that members applying for upgrading facilitate the prompt processing of their applications by specifying at least the minimum number of qualified references and providing complete information. Those charged with responsibility for approving or denying requests for admission or transfer have for their guidance a manual which has been developed and improved through the years. It has insured consistency and uniformity of action, and maintenance of the stature of the grades. You are urged, in preparing applications, to keep in mind that an applicant's qualifications must be judged by the information contained in the written material presented for consideration, which normally consists of the applicant's own statements and the recommendations and comments of his qualified references.

It is recommended that applicants provide their references with a summary of their technical training and experience because, frequently, those named as references have an incomplete recollection of an applicant's professional history. In the absence of such recollection, the persons named as references must request it, or restrict their comments, to the possible disadvantage of the applicant.

The Application of Damping to Phonograph Reproducer Arms[*]

WILLIAM S. BACHMAN[†]

This paper is published with the approval of the IRE Professional Group on Audio, and has been secured through the co-operation of that Group.—*The Editor.*

Summary—**Large forces are developed at the stylus tip of a conventional phonograph reproducer arm because of excitation of the resonance of the arm mass with the suspension compliance. This paper presents an analysis of the problem and describes a reproducer-arm design in which mechanical resistance is introduced in the pivots. By this means, control of the arm resonance is obtained without increasing the stylus-tip impedance of the reproducer.**

THE STYLUS-BEARING force of a disk reproducer upon the record must be small to limit the bearing pressure to reasonable values. This low force is called upon to hold the stylus in contact with the groove against the dynamic forces developed at the stylus point at arm resonance, and to move the reproducer arm about its vertical pivot along the spiral path which the record groove presents. By providing damping in both the horizontal and vertical pivots, this resonant force is greatly reduced, improved resistance to external shock is obtained, and protection against damage from accidental release of the reproducer head is achieved.

At low frequencies, say below 500 cps, the mechanical system of a phonograph reproducer arm and pickup cartridge may be represented by a mass suspended on a spring. In Fig. 1(a) (see following page), *m* represents the effective mass of the arm and cartridge assembly, referred to the stylus point. This is always less than

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the weight of the assembly since it is partly supported at the far end by the pivot about which it rotates. The compliance (the reciprocal of stiffness) of the stylus suspension is represented by c.

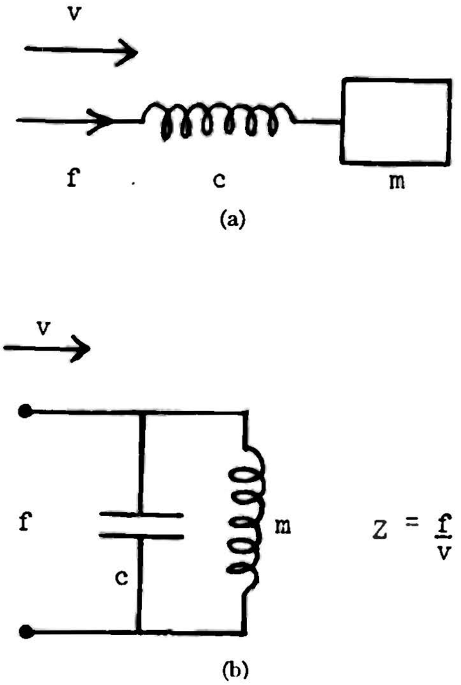

Fig. 1—(a) Mechanical schematic diagram of a conventional reproducer arm and cartridge at low frequencies.
c = the needle-suspension compliance of the reproducer cartridge
m = the effective mass of the arm and cartridge assembly, referred to the stylus tip
f = the force developed at the stylus tip
v = the velocity of motion of the stylus tip.
(b) Electrical equivalent of mechanical system of 1(a).
Z = the mechanical impedance at the stylus tip.

Below the resonant frequency of the system, which is often in the 30-to-60-cps region, the motion of the mass corresponds to the motion of the driving point. In other words, the arm and cartridge follow the slow progress of the spiral groove. Above the resonance, the system becomes mass controlled, and the arm does not follow the rapid undulations which the modulated groove imposes upon the reproducer stylus. This difference in motion between the stylus and the arm provides the stimulation of the pickup, to which the output voltage is proportional.

The operation of the system may also be described in electrical terms by referring to the analogous circuit in Fig. 1(b). The mass is analogous to inductance, compliance to capacitance, force to voltage, and velocity to current. The unidirectional motion which describes the radial motion of the arm in following the spiral groove corresponds to dc in the electrical system. The alternating velocity imparted to the stylus by the groove modulation corresponds to ac in the electrical network. Above the resonant frequency this velocity (or current) divides between the compliance, c, and mass, m, practically all of it admitted by the compliance in the useful range of the reproducer. The output voltage is proportional to the velocity to which the compliance is subjected in a magnetic type of reproducer, or to the integral of this velocity in a displacement-sensitive reproducer.

At the resonant frequency of the circuit of Fig. 1(b), the impedance, Z, reaches very high values, limited only by the Q of the system. The Q of the mass element is very high. There is usually some dissipation in the suspension compliance, however, but its value must be limited if the mid-range impedance of the system is not to be made too high.

To indicate schematically where the dissipative element appears, the mechanical system is shown in Fig. 2(a). This mechanical system schematic shows that deflection of the suspension spring is accompanied by work done in the friction or mechanical resistance element r.

The electrical equivalent of this mechanical system is shown in Fig. 2(b).

As a practical example, let us assume a suspension compliance of 10^{-6} cm/dyne and an effective arm mass, referred to the stylus tip, of 20 grams. These are in the range likely to be encountered in actual practice. Such an arm and cartridge assembly would have an arm resonance frequency of

$$f = \frac{1}{\sqrt{4\pi^2 mc}} \frac{1}{\sqrt{4\pi^2 \times 20 \times 10^{-6}}} = 35.6 \text{ cps.}$$

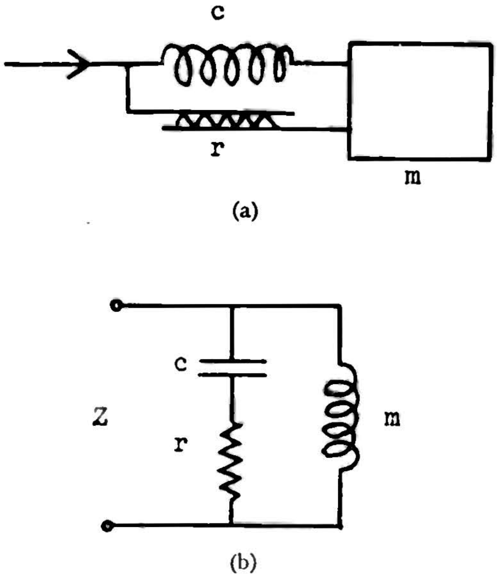

Fig. 2—(a) Mechanical schematic of phonograph reproducer arm and cartridge, with damping in the needle suspension.
r = the effective mechanical resistance resulting from the dissipation in the needle suspension. (b) Electrical equivalent of mechanical schematic in (a). Above resonance the impedance at the needle point Z can never become lower than r.

To critically damp this resonance, the value of r would have to be

$$r = \sqrt{\frac{4m}{c}} = \sqrt{\frac{4 \times 20}{10^{-6}}}$$

$$= 8{,}950 \ \frac{\text{dyne sec}}{\text{cm}} \ \text{(mech. ohms).}$$

Now, inspection of the circuit in Fig. 2(b) shows that, above the resonant frequency, the impedance approaches r. (X_m gets very large and X_c gets very small.) Suppose that a velocity of 5 cm/sec rms were imposed upon the stylus. This velocity is considerably below the peak program level encountered in most records. The force at the needle point would be

$$f = rv = 9{,}850 \ \frac{\text{dyne sec}}{\text{cm}} \times 5 \ \frac{\text{cm}}{\text{sec}}$$

$$= 44{,}600 \text{ dynes or } 45.5 \text{ grams.}$$

If the included angle of the groove were 90°, the upward component of this lateral force would be equal to it, and the needle-bearing force would have to be in excess of $45.5 x \sqrt{2}$ grams (45.5 is the rms value) to insure contact with both sidewalls of the groove. Such a value of needle force is absurd, particularly for microgroove records, so it becomes obvious that effective damping of the arm resonance cannot practically be obtained by this method.

It has been usual practice to increase arm mass to move the resonant frequency farther below the desired transmission band. This reduces the incidence of arm-resonance excitation by program material, but the resonant impedance is thereby increased, which further increases the susceptibility to jumping as a result of accidental mechanical shock.

If, in the circuit of Fig. 2(b), the resistive element were inserted in series with the mass element, as shown in Fig. 3(a), it would not affect the driving-point impedance of the system above the resonant frequency. In other words, the impedance above resonance of the circuit of Fig. 3(a) would be the same as that of Fig. 1(b), namely, approaching X_c.

Mechanically, Fig. 3(a) is represented by Fig. 3(b). The proper functioning of the system in the useful signal frequency range, as mentioned before, depends upon all of the imposed motion, v, being accommodated by the spring, c. Only below the resonant frequency is the motion of m significant. Putting the resistance in this position does mean that it will have to "carry the dc," or, in other words, to accommodate the motion imposed by the slow radial progress of the spiral. The velocity of this spiral is quite low. Suppose the record is turning at 78 rpm, with a spiral pitch of 100 lines to the inch. The radial velocity will be

$$v = \frac{1 \text{ in}}{100 \text{ rev}} \times \frac{78 \text{ rev}}{\text{min}} \times \frac{\text{min}}{60 \text{ sec}} = 1.3 \times 10^{-2} \text{ in/sec}$$

$$\text{or } 3.3 \times 10^{-2} \text{ cm/sec.}$$

The force necessary to move the arm at this velocity against resistance r is

$$f = rv = 8{,}950 \times 3.3 \times 10^{-2} = 295 \text{ dynes or } 0.3 \text{ gram.}$$

This is a satisfactorily low value, and furthermore, it is still lower with fine groove records turning at lower speeds.

From the mechanical schematic in Fig. 3(b), it is seen that the mechanical resistance element must be installed between the arm and the motorboard. It could be applied against any part of the arm, or at its pivots, in a wide variety of forms. The idea of some friction connection in the pivots, or elsewhere, is violently opposed to the usual concept of a reproducer arm. In fact, failure of many arms to operate satisfactorily at the low bearing forces which LP microgroove records impose can be traced to excessive pivot friction. This friction is quite different from the desired mechanical resistance. It is true that friction causes energy to be dissipated as heat, as does mechanical resistance. The big difference is that pure mechanical resistance does not change in value as the velocity is varied. In ordinary rubbing friction, the resistance offered varies violently with the imposed velocity. A good familiar example is the large difference between starting friction and running friction, which is observed in bearings. As an example of linear mechanical resistance, consider a boat, floating in water. The resistance it offers is easily demonstrated by the work the engine has to do to move it at constant speed through still water and dead air. Yet this same boat may be moved, slowly, to be sure, with a surprisingly small force in still water and dead air. In this example, the friction of the boat moving through the water is linear, assuming that the velocity range does not extend into turbulence of the water. The friction behaves as a true mechanical resistance, in which the velocity of motion is proportional to the applied force.

While friction is one of the most severe restraints in the design of many mechanical systems, it is almost paradoxical that linear mechanical resistance is very

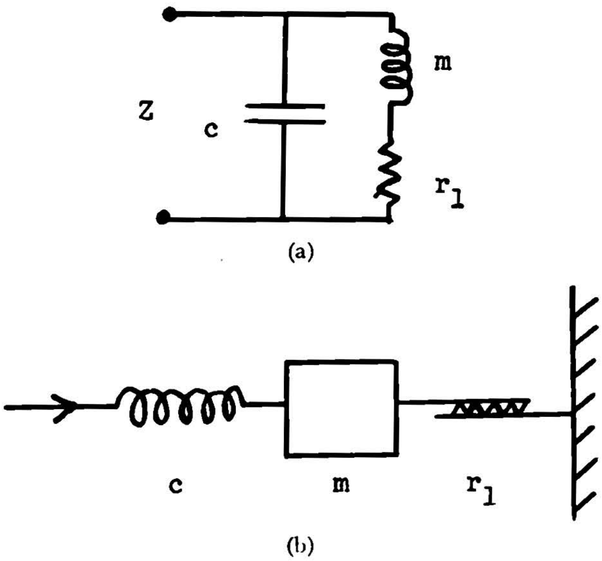

Fig. 3—(a) Modification of the circuit in section (b), which avoids raising the input impedance above resonance without sacrificing the effect of r upon damping. r_1 is a new circuit element, and not the resistance due to damping in the suspension compliance. (b) Mechanical schematic of electrical circuit of section (a). r must be inserted between the arm mass and the record or motorboard.

difficult to obtain. Probably the purest form of mechanical resistance is that which obtains from the motion of a short-circuited conductor in a uniform magnetic field. This is "pure" only in the sense that it is linear. It cannot be separated from the mass of the conductor through which it is developed.

It is possible to compute the amount of mechanical resistance which a given conductor will develop in a magnetic field by using the two basic relations pertaining to a moving conductor in a uniform magnetic field, viz.,

$$f = Bli \tag{1}$$

$$e = Blv, \tag{2}$$

where

f = the mechanical force
b = the flux density
l = the length of the conductor
i = the current in the conductor
e = the voltage induced in the conductor
v = the velocity of motion of the conductor.

Now,

$$r = \frac{f}{v} = \text{mechanical resistance.} \tag{3}$$

Substituting (1) and (2) in (3),

$$r = \frac{B^2l^2i}{e} = \frac{B^2l^2}{R}, \tag{4}$$

where R is the electrical resistance of the conductor.

Now,

$$R = \frac{pl}{A}, \tag{5}$$

where

p = specific resistivity of the conductor
l = length of conductor
A = cross sectional area of conductor.

Substituting (3) in (4),

$$r = \frac{B^2lA}{p} = \frac{B^2V}{p} = \frac{B^2M}{pd}, \tag{6}$$

where

V = volume of conductor
M = mass of conductor
d = density of conductor material.

The ratio M/r has the dimension time and is analogous to the time constant L/R of an electrical circuit comprising these elements.

Solving (6) for the time constant:

$$\frac{M}{r} = \frac{pd}{B^2}.$$

Assuming a copper ring type of conductor in an annular air gap having a flux density of 10,000 lines per square centimeter,

$$\frac{M}{r} = \frac{1.6 \times 10^{-6}\text{ ohm cm}}{1} \times \frac{8.9\text{ gram}}{\text{cm}^3} \times \frac{\text{cm}^4}{10^{-8}\text{ volt}^2\text{ sec}^2}$$

$$\frac{M}{r} = 14.2 \times 10^2 \frac{\text{ohm cm}^2\text{ gm}}{\text{volt}^2\text{ sec}^2} \times \frac{\text{dyne sec}^2}{\text{gram cm}}$$

$$\times \frac{\text{volt}^2}{\text{watt ohm}} \times \frac{\text{watt sec}}{\text{joule}} \times \frac{\text{erg}}{\text{dyne cm}} \times \frac{\text{joule}}{10^7\text{ erg}}$$

$$= 142 \times 10^{-6}\text{ sec.}$$

If the size of conductor were chosen so that 100 mechanical ohms would be developed, the mass of the conducting ring would be

$$M = \frac{M}{r} \times r = 142 \times 10^{-6}\text{ sec} \times \frac{100\text{ dyne sec}}{\text{cm}}$$

$$= 14.2 \times 10^{-3}\text{ gram.}$$

The presence of mass with the resistance in this mechanical system is analogous to the presence of inductance in an electrical resistor. A resistor of 100 ohms having 14.2 millihenries built in would be far from a noninductive resistor.

Another, more attractive, method of obtaining linear mechanical resistance is through the use of viscous liquids. The resistance may be obtained by moving an impeller through a liquid, forcing the liquid through an orifice, or utilizing the viscous fluid as a film in shear. One difficulty to which these methods are subject is the change of viscosity with temperature. While this effect is large with most petroleum oils, the effect is much smaller in silicone oils. Since the specific value of the mechanical resistance is not critical in this application, either type of oil may be used over a reasonable temperature range.

In Fig. 4, a cross-sectional view of a design using a fluid film in shear is shown. The two concentric surfaces which bound the film are those of a ball and socket. The ball is part of the arm and the socket part of the mounting base. The arm is suspended on the point of a stud which is part of the base. This point is at the center of both the ball and socket, and above the center of gravity of the arm. A clearance of about 0.006 inch is maintained between the surfaces of the two spherical segments, and this space is filled with high-viscosity oil (having a viscosity of approximately 50,000 centistokes).

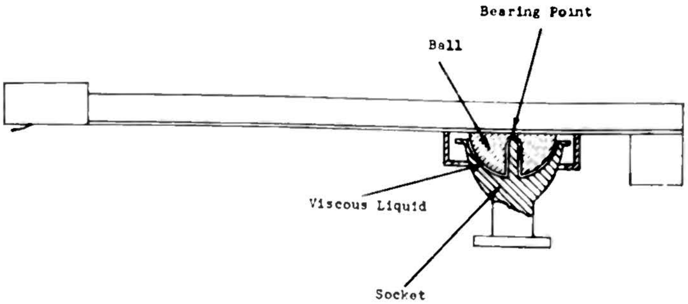

Fig. 4—Cross-sectional view of phonograph reproducer arm having viscous film damped pivot.

It is evident that this design provides mechanical resistance in both the lateral and vertical planes. While the theoretical analysis of the mechanical system at the beginned of this paper treated only the conditions obtaining in the horizontal plane, it is obvious that a resonance in the vertical plane will also be observed. This may or may not occur at the same frequency as the lateral resonance, depending upon the ratio of vertical to lateral compliance and the effective mass at the stylus tip in the two planes. Usually the vertical resonance is near the lateral resonance so that, substantially, the same value of mechanical resistance is required for its damping. Having damping in the vertical plane also provides protection from damage due to accidental release of the arm. The rate of fall is held to a low value so that the shock of contact is small and no bouncing results. For a reproducer having a needle force of 5 grams, and a damping resistance of 8,950 mechanical ohms, the rate of descent will be

$$V = \frac{f}{r} = \frac{5 \times 10^3 \text{ dyne cm}}{9 \times 10^3 \text{ dyne sec}} = 0.55 \text{ cm/sec.}$$

A similar retarding effect is obtained in the lateral plane which increases the resistance to lateral shock. To put it another way, the tendency of a reproducer arm to function as a seismograph is arrested.

The mechanical resistance obtained by fluid films is proportional to the area of the film and approximately inversely proportional to the film thickness. It has been observed that with thicker films and higher viscosity liquids a significant amount of compliance appears along with the resistance. If this compliance were too large, it would serve to uncouple the resistance element from the system. Small values of compliance, on the other hand, are helpful in that they permit the arm to follow severely warped or eccentric records readily.

It is interesting that the amount of mechanical resistance used in this reproducer arm is not a critical value. The upper limit of resistance is reached when it interferes with tracking records having reasonably small values of eccentricity or warpage. With the usual values of suspension compliance and mass, this would occur at several times the amount of resistance necessary to critically damp the arm resonance. At the other extreme, where the resistance approaches zero, the arm merely reverts to a conventional one, in which there is very low pivot friction. If the design is such that the resonance of the arm and suspension compliance occurs below the desired transmission band, the variation in resonant response, resulting from change in the mechanical resistance, is of little importance. Between these extremes, a wide range of improved performance exists. Even a resistance in the order of one-sixth of the critical value will cut the Q of the resonant system significantly, with a corresponding improvement in stability as a result.

Fig. 5 shows the performance of an experimental arm similar to the one shown in Fig. 4. A light arm, having approximately 20-grams effective mass at the stylus tip, was used with a crystal cartridge whose compliance was approximately $.5 \times 10^{-6}$ cm/dyne. The light arm and stiff cartridge were chosen so that the resonant frequency would be high enough to avoid errors due to pointer vibration in the indicating instruments.

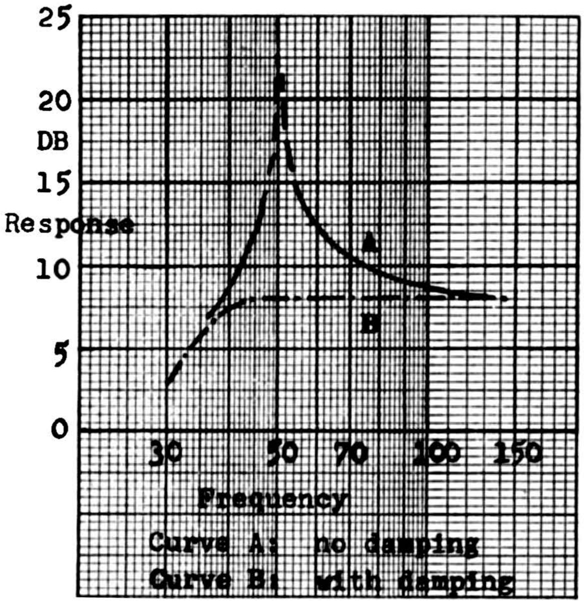

Fig. 5—Response of experimental arm with and without damping.

Without damping, the dynamic forces developed near resonance were so large that the stylus was forced out of the groove. For this reason it was not possible to measure the true resonant rise, and the curve therefore shows, with dashed lines, an estimated response in this region.

Fig. 6 is a photograph of a commercial design of a reproducer arm based upon the principle illustrated in Fig. 4. In this arm, the thumb screw over the pivot point permits adjustment of the film thickness to accommodate a wide range of temperature.

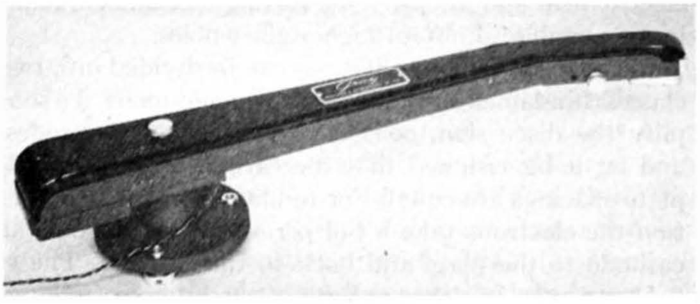

Fig. 6—Photograph of commercial design of a viscous damped reproducer arm.

The application of linear mechanical resistance to the pivots of a phonograph reproducer arm provides effective means for damping the low-frequency arm resonance. When this resonance is brought under control, it is no longer necessary to have a large excess of needle force on the record over that required to follow the desired modulation of the groove.