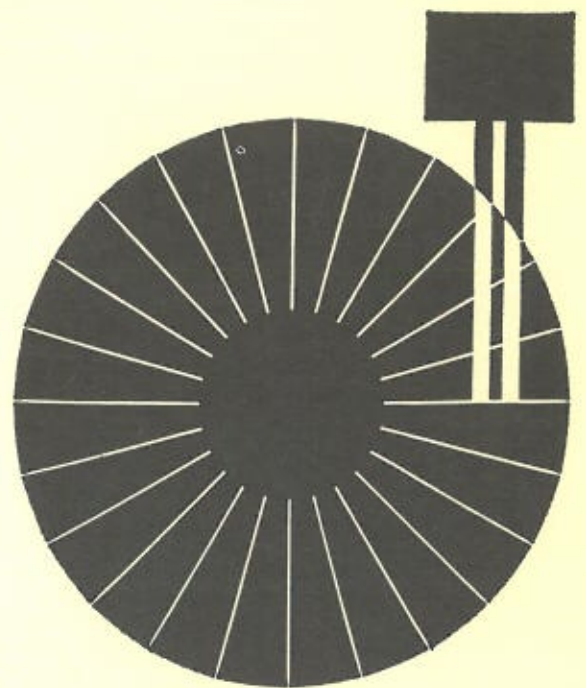
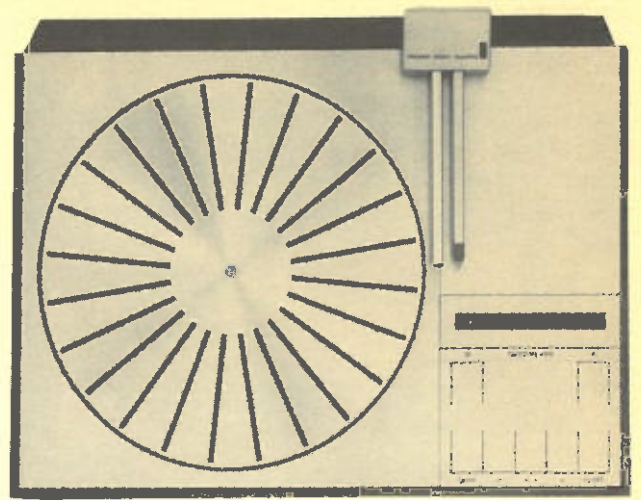


BEOGRAM 4002
Design Story



Bang & Olufsen

THE DESIGN STORY OF THE BEOGRAM 4002 -
AN INTEGRATED RECORD PLAYBACK ENSEMBLE WITH
ELECTRONICALLY CONTROLLED TANGENTIAL ARM

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FORM FOLLOWS FUNCTION

The successful engineer - whatever his specialty - must first consider the primary purpose, the ultimate use, of the product or project he is designing. For example, a construction engineer should primarily be concerned with the question of how to get across to the other side, rather than get too involved with the design of bridges.

So too with the design of the Beogram 4002. The objective was to devise the best and easiest way to play a record, rather than to design a new record player.

"Best" in terms of technical finesse.

And "easiest" in terms of operation.

We believe that the Beogram 4002 achieves these objectives.

And when functions are optimized, as in the Beogram 4002, the result is bound to be aesthetically pleasing - because "form follows function". Moreover, as is customary in product development at Bang & Olufsen, the designer was an integral part of the product team throughout the development of the Beogram 4002.

With its electronically controlled tangential arm, the Beogram 4002 is the most easily operated turntable in the world. The technical specifications speak for themselves, as does the performance level - the sound reproduced is as close to the original as modern technology permits.

This booklet is not a sales brochure.

Its purpose is to acquaint the reader with some of the alternatives open to the designer of a modern high quality gramophone. With such insight, the reader will be better equipped to appreciate the solutions chosen for the Beogram 4002 and especially to understand why Bang & Olufsen designed a totally integrated gramophone.

Bang & Olufsen has been a manufacturer of turntables since 1936. Looking back over the years, we find a diversified collection of units. From simple turntable units designed solely by Bang & Olufsen, to license-built automatic record changers, to the units that characterize the Bang & Olufsen line today.

Since the appearance in 1958 of our first stereo pickup cartridge, the SP1, we have continued to be one of the few manufacturers to consistently integrate the tone arm and the pickup cartridge. We have been able to do this because we have always

had a wide range of quality pickup cartridges at our disposal.

By developing a design of our own, we have created a line of turntable units that is characterized by its integrity.

Avoiding the extremities of construction and styling, we have always insisted that playing records should be a simple, straightforward procedure.

And we have always been aware of the fact that our equipment is for use in the home.

DEFINING THE PROBLEM

How did the idea of making a minimum compromise record player first arise?

The starting point was a certain amount of dissatisfaction among development engineers with the seemingly inherent necessity for major compromises in the design of a turntable. So one day, we put a clean sheet of paper on the drawing board and decided to design the right player, from stylus tip to amplifier connection.

The task was assigned to an experienced development team which began by defining and evaluating the project.

Previous experience as based on mechanical designs and mechanical solutions to practically every turntable function - all of which required a number of manual operations.

Thus, the development team decided to build an electronically controlled unit. A natural development, since the use of electronics would enable us to develop a high performance turntable of unprecedented quality.

In 1968, the engineering team began the task of developing a no-compromise, electronic gramophone featuring absolutely top specifications and obsolescence-proof design. The start of the project was preceded by evaluating consumer demands for a high quality turntable unit because the success of the product would ultimately depend upon its reception by the consumer.

The people for whom the Beogram 4002 was intended are those who want to extract all information from their records without having anything added to the original sound. In short, they demand utmost fidelity in sound reproduction. The Beogram 4002 was designed also for those who appreciate the ability of a gramophone to handle records gently; a gramophone whose operation is simple and reliable and whose physical appearance graces any home.

SYSTEMATIC APPROACH

The task, thus formulated, would be a challenge to any development team because designing a product whose main objective is perfection is a rare task in industry. So work was begun with a great deal of enthusiasm. But enthusiasm did not overpower scientific discipline. Definition of the task, problem analysis and systematic formulation of the solution proceeded in an orderly fashion.

The task was split into a number of systems:

- Pickup system
- Tonearm system
- Turntable system
- Automatic control system
- Operation system
- Domestication (by which we mean all features and functions that make the product suitable for use in a domestic environment - both from an aesthetic and a functional point of view).

These systems were to be integrated into a common design idea in which additional features had to be of the highest calibre:

- Long-term stability
- Ease of service
- Production efficiency
- Ease of operation

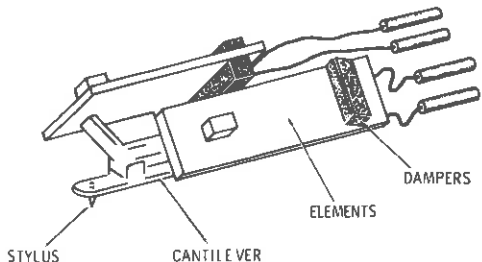
A target formulation was drawn up for each system. At regular intervals these were evaluated and compared with the target formulations for the other systems so the work, as it progressed, was co-ordinated for optimum results.

In the interest of clarity, each system will be described separately.

THE PICKUP CARTRIDGE

Pickup cartridges can be divided into three groups, according to their construction principle:

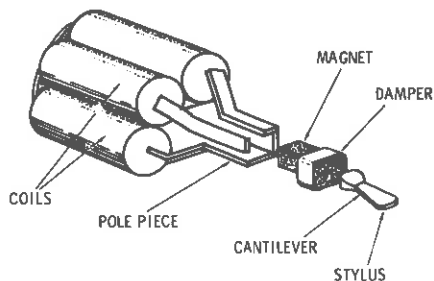
1. Magnetic cartridges (used in hi-fi components)
2. Ceramic/Crystal cartridges (used mostly on low-priced equipment)
3. Semiconductor cartridges (relatively new and not in popular use).



Generating Principles

The mechanical vibrations induced in the stylus by the groove modulations may be converted into electrical energy in a variety of ways.

Ceramic or crystal cartridges utilize piezo-electric force (consisting of elements which, when slightly flexed, produce an electrical voltage).

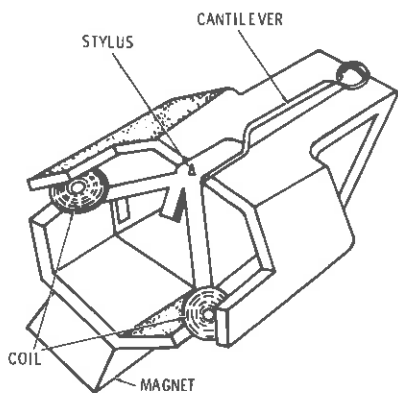


Magnetic cartridges utilize one of the many variations on the basic theme that electricity can be generated by moving a wire near a magnet (or vice versa).

There are therefore several construction principles for magnetic cartridges, each depending on whether the stylus unit causes movement to begin in the induction coil, the iron poles or the magnet (one element in relation to the other two).

A system gets its name from the principle utilized:

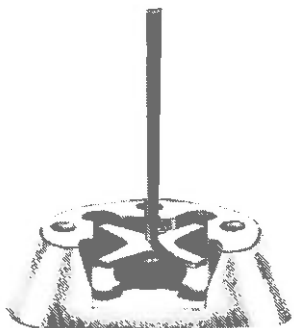
- Moving-magnet
- Moving-coil
- Moving-iron



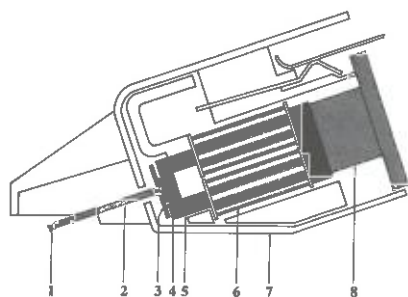
There are no marked advantages in the generating capabilities of one system over another. But, since a major aim of any cartridge is a low effective tip mass (discussed overleaf), the cartridge whose generating elements can be minimized without undue loss of output voltage seems most attractive.

The Moving Micro Cross (patented MMC principle)

Bang & Olufsen chose a moving-iron generating system (the patented Moving Micro Cross principle) for their first stereo cartridge, the SP1 developed in 1958, because engineers found that this special symmetrical MMC system renders the cartridge highly insensitive to external hum fields.



The MMC system has an x-shaped armature which is driven by the cantilever and stylus.



- | | |
|---------------------------------------|--------------------|
| 1. Nude Pramanik diamond [®] | 5. Pole pieces (4) |
| 2. Low mass beryllium cantilever | 6. Induction coils |
| 3. Moving Micro Cross | 7. Mu-metal screen |
| 4. Block suspension | 8. Hycomax magnet |

The cartridge body is encapsulated and contains the fixed magnet and four coils whose poles are close to the tips of the armature cross-arms. The Moving Micro Cross generating system enables miniaturization, while still maintaining a sufficiently high output voltage. For these reasons, the design team retained the MMC principle in the design of Bang & Olufsen's most ambitious record play-back ensemble.

Evaluating Pickup Cartridges

Evaluating the quality of a pickup cartridge is very difficult, for two reasons. One, the technical specifications are inter-related and in many cases mean very little out of context. Two, technical data alone is no basis for evaluation. Two systems with identical specifications can present different sound images. But here it is fair to point out that at the top quality level, differences in sound, while audible, are not easily expressed in words; neither are they a matter of "better" or "worse" - except perhaps subjectively. All that can be said, objectively, is that they are "different".

The following section discusses some of the relevant specifications which were given special consideration during the development of the pickup cartridge for the Beogram 4002. Furthermore, it specifies the inter-relationship between various data and the relative importance of each, with regard to an important objective quality parameter, namely, record and stylus wear.

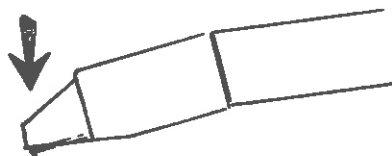
Tracking Force

A widely used parameter in the quality grouping of pickup systems is the recommended tracking force. Many attach exaggerated importance to this parameter. This places pickup systems with recommended tracking force values below 1.0 gram in the highest quality brackets, those between 1.0 and 2.0 grams second, and 2.0 - 5.0 grams in the lowest group.

Accomplishing the highest quality in any electro-mechanical device is a question of know-how and patience. It is necessary to balance the importance of the various parameters that affect overall quality. Hence it is wrong to attach the greatest importance to one parameter only, in this case the vertical tracking force, referred to below as VTF.

For example, a test may reveal greater record wear with a pickup that requires a VTF of 2.5 grams, than with one requiring 0.7 gram. That wear has occurred is a fact. But this test cannot determine that the

VTF



stylus pressure is solely responsible. The fact is that record wear is influenced by many other factors. What counts as far as the turntable unit and pickup cartridge are concerned is effective stylus mass, the shape and polish of the stylus, compliance, tone-arm design, skating effect and compensation, and bearing friction effects. Regarding record wear, the record itself has a contributory share, determined by such factors as modulation depth, diameter and record surface condition (dust, grease etc.). All these factors, therefore, contribute to record wear and VTF, but there is no direct connection between record wear and VTF.

Compliance

Another popular parameter is the compliance (or elasticity) of the stylus suspension. This again is a question of removing a detail from its context. Reproduction of low frequencies makes demands on compliance, whereas compliance is of little significance as far as high frequencies are concerned.

In order to illustrate the importance of compliance, Bang & Olufsen devised an experiment using a pickup whose compliance was 0.1×10^{-6} cm/dyne. No difference was noted at frequencies above 10 kHz, compared with a pickup having a compliance of 25×10^{-6} cm/dyne.

A high-compliance pickup must necessarily operate at a commensurately low tracking force. If the tracking force becomes too large for a given compliance, the pickup cartridge will simply sink down onto the record as the stylus bends up into its mount.

Before the beginning of the stage at which the stylus bends all the way back, increased tracking force will cause distortion due to the fact that the movable stylus assembly does not center correctly with respect to the static elements of the pickup.

High compliance is therefore a necessary condition for the reproduction of the lowest frequencies. It also sets the upper limit of the tracking force. However, in itself compliance is not a criterion of quality.

Tracking Force and Compliance

A study of the connection between tracking force and compliance is in order. If, in comparing two pickup systems, all other factors are kept identical and constant, the lowest tracking force and the highest compliance are directly dependent on each other for low frequencies. Whether the pickup having the

lower tracking force of the two also tracks better and causes less record wear is an entirely different question which must be regarded as part of a greater whole.

Since it is impossible to make massless tonearms, any irregularity in the record surface will cause the stylus assembly to make large excursions, resulting in inter-modulation distortion and occasional bumps. High compliance therefore requires an absolutely flat record, which is a difficult thing to find.

Tracking Force and Record Wear

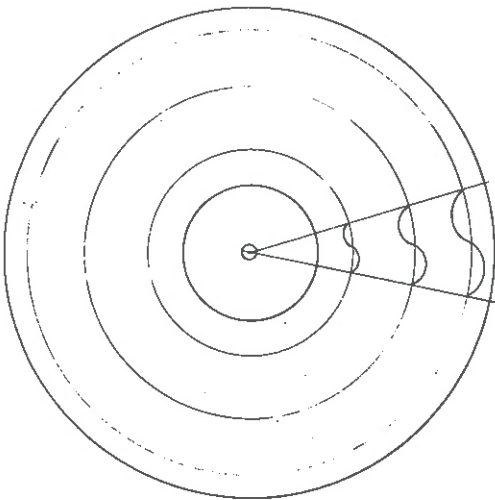
The tracking force helps to maintain contact between the stylus and the record groove wall. If you go below the MVTF (minimum vertical tracking force), the stylus will periodically loose contact with the groove wall as it will be thrown out by the modulation of the groove. Such jumping is exceedingly dangerous to the groove. One must therefore be very careful not to go below this minimum stated value. Actually, a slightly higher tracking force is preferable. It should be remembered that the dynamic force acting on the groove at high frequencies is several hundred times higher than the vertical tracking force. Groove deformity (wear) is therefore due to factors entirely different from the vertical tracking force provided the latter does not exceed approximately 2 grams (for an elliptical stylus).

What is Record Wear?

Record wear is groove deformity which primarily impairs the high-frequency response. A worn record is characterized by distorted high-frequency response and lack of "transparency".

A closer study of record wear reveals the fact that wear always begins on the inner grooves of the record. This is due to the fact that the mechanical wavelength of the recorded frequencies is shorter on the inner grooves than on the outer ones. It is particularly the high frequencies which are damaged. The reasons for this will be discussed shortly.

For the sake of completeness it should also be mentioned that too little or too much antiskating force will concentrate the wear either in the inner or the outer groove wall.



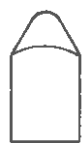
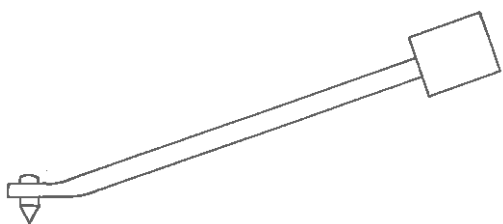
Effective Tip Mass (ETM)

Effective tip mass, referred to below as ETM, is the mass which the groove must shift during play. The entire mass of the diamond contributes to the ETM. The cantilever, functioning as a kind of lever, contributes by approximately one-third of its mass. Depending on the design principle of the pickup type in question, a greater or lesser share of the generating element (magnet, coil or iron) is added to the ETM. The cantilever length and the intrinsic mass and shape of the generating element also influence the amount of weight added to the ETM. It is of greatest importance to achieve the lowest possible ETM. We will discuss the reason for this after we have considered the chances of reducing the ETM. However, its value can never become too low. The objective is $ETM = 0$.

The diamond, which contributes its entire mass, may either be framed in steel or in aluminium (low-priced styli), or it may be a naked diamond. In addition to its very low mass, the naked diamond is characterized by being more resistant to wear than the framed types. The reason for this is that it is actually possible to orient the diamond's crystal structure during cutting and polishing to place the hardest surfaces in contact with the groove walls.

The cantilever, like all other components of the pickup system, is a compromise between a number of factors. Length, weight and strength of material must be accurately matched. This is necessary to avoid resonances and obtain better resistance to mechanical damage. It is thought that about 80% of all stylus assemblies are replaced because of bent or broken cantilevers, rather than because of worn diamonds. (Here we disregard cheap, competitive styli of soft sapphire or - as we have actually seen - steel needles.)

The generating element must be as small and as light as possible. It is extremely difficult to make a lightweight generating element in pickup types based on the moving magnet and moving coil principles. This is because, in order to deliver a reasonable output signal, a pickup cartridge requires either a high-power miniature magnet or, a coil with many turns. In both cases it is difficult to keep the mass of the generating element sufficiently low.



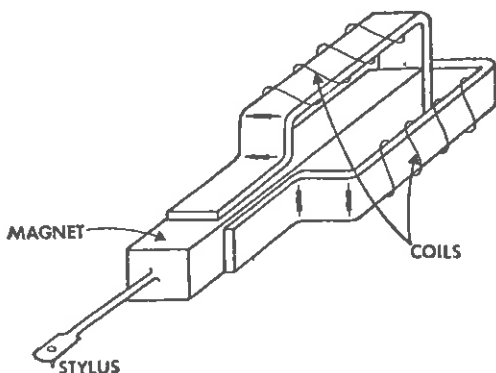
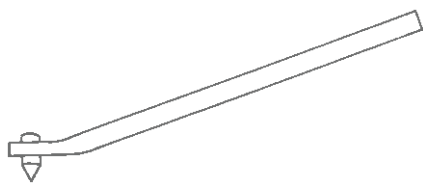
NAKED DIAMOND
~ 0.09 MILLIGRAMS

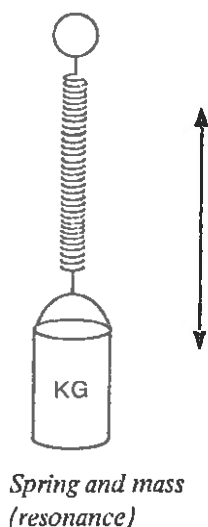


ALUMINUM FRAMED DIAMOND
~ 0.25 MILLIGRAMS



STEEL BUSHED DIAMOND
~ 0.40 MILLIGRAMS





Mass and Resonance

Every mechanical system has one or more resonant frequencies. Just think of an old car; it usually has several. Every mechanical element will attempt to vibrate at its natural resonance when activated by some outside force. A resonance is characterized by the fact that the mechanical structure requires only very little energy applied to it in order to continue its resonant vibrations.

Resonance may occur both in mechanical and in electrical systems. Resonances may be either wanted or unwanted. You may prevent them if they are unwanted or promote them if you find them useful. In motor cars, resonances are absolutely unwanted and extremely annoying. In the case of churchbells, on the other hand, resonance is a highly desirable quality, and so too is a wealth of overtones (harmonics). They lend character and individuality to the bell.

Stylus Assemblies - Mass and Resonance

A stylus assembly - in other words: the diamond, cantilever and generating element - like any other mechanical system has a resonant frequency of its own. But the problem is that in this case we certainly do not want the stylus assembly to resonate. The stylus assembly must serve as a mechanical link between the record groove and the pickup system. We want the vibrations that are registered in the record picked up, no sounds introduced by the pickup system itself. The pickup is a transducer; converting the mechanical vibrations of the record to electrical signals that may be amplified to a suitable level and thereafter converted into audible mechanical vibrations via the loudspeaker. Resonances occur both in the speaker cones and in the cartridge's stylus assembly, and in both places they are unwanted.

Although both the pickup and speaker convert mechanical vibrations into electrical ones and vice versa, one essential factor occurs only in the pickup system: it causes wear to its mechanical signal source (the record).

What Causes Record Wear?

A number of tests show that a high ETM (effective tip mass) is one of the most serious causes of record wear, and this is most pronounced in the inner grooves. It is especially the high frequency passages of the record that are damaged. This type of wear is relatively easy to determine by listening. High frequen-

cies become more difficult to reproduce in this portion of the record whereas the deep and mid-range tones are equally difficult to reproduce over the entire record. Additionally, wear may be expected to be identical for equally strongly modulated passages.

It is possible that a high MVTF (minimum vertical tracking force) value is caused by excessive ETM, and is necessary simply to hold the stylus in the groove. Such a pickup may well have medium and low range tracking comparable with that of a pickup which has a low MVTF.

A pickup with high effective tip mass (ETM) will damage high frequencies more than one with a low ETM value and will do so the first time the record is played - especially on the inner grooves. Increased tracking force can reduce the audible distortion as mistracking will then occur in fewer passages, but the wear level will remain largely unchanged as the forces to which the groove is exposed are largely unchanged (see Tracking Force and Record Wear).

It is important to understand that the damage to the high frequencies of the groove is due to strong resonances in the cartridge's stylus assembly in the frequency range between 12,000 and 16,000 Hz because of excessive ETM.

Even if pickup stylus assemblies involve ETM values only of the order of 0.5 - 2.0 mg in dynamic systems manufactured by companies of good standing, it nevertheless applies that: relatively high stylus mass produces relatively low resonant frequency down in the audible treble range. A relatively low ETM value produces a resonance that is high in frequency. The objective here must be to increase the frequency of that resonance to well up above the audible range.

If such a record is subsequently played with a better pickup which has a higher resonant frequency, the record wear caused by the inferior pickup will distort the reproduction, causing even critical listeners to misjudge an otherwise superior pickup.

Keep This in Mind When Evaluating a Pickup Cartridge

Always use only new virgin records in critical and decisive listening and measuring tests. Otherwise you will be chained to the past, and an objective appraisal will be impossible.

What Characterizes a Low-ETM Pickup?

What you should look for is a pickup that has an absolutely flat amplitude characteristic (frequency curve) throughout the audible range. This indicates that resonances have been placed outside the audible range. Such a pickup has a very low ETM value, and will produce very few phase errors in the transfer characteristic. This can be seen in a good square wave, which in turn means better transient response, a characteristic of a good quality pickup.

Listen Critically

It goes without saying that in listening tests on pickup systems, it is necessary to ensure that the amplifier system and monitor speakers are of optimum and confirmed quality.

It is a question of "recorded" versus "live". In other words: the greatest possible identity with the concert hall. Just as with speakers, any form of colored sound or special effects are unwanted.

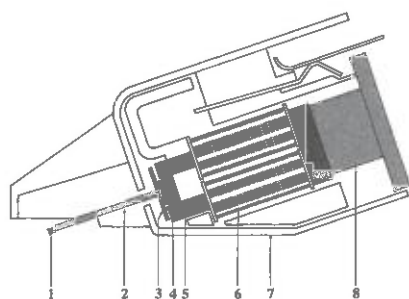
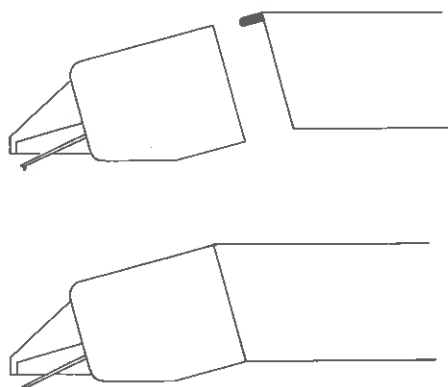
The A-B test between two systems requires a comparator to compensate between different output levels, otherwise you will invariably decide in favor of the louder playing system, just as with speakers.

The MMC 6000

Perhaps it is appropriate to discuss in more specific terms, the pickup cartridge which is an integral part of the Beogram 4002. This, for two reasons. One, the Beogram 4002 will accept no other cartridge but one of the Bang & Olufsen MMC line. Two, the MMC 6000 is one of the most outstanding cartridges on the market. The MMC 6000 plugs directly into the tangential arm of the Beogram 4002 without the use of a mounting bracket (which adds unwanted mass).

An Integrated System

The MMC 6000 is manufactured as a totally integrated sealed unit. This means that the moving parts and the static mechanism of each MMC 6000 are adjusted, balanced, and sealed as one unit at the factory. The stylus assembly is therefore a permanent part of the cartridge and cannot be replaced. The decision to design an integrated cartridge was made after long deliberations on how to construct a cartridge with an extremely low effective tip mass. It was found that integration and sealing at the



- | | |
|---------------------------------------|--------------------|
| 1. Nude Pramanik diamond [®] | 5. Pole pieces (4) |
| 2. Low mass beryllium cantilever | 6. Induction coils |
| 3. Moving Micro Cross | 7. Mu-metal screen |
| 4. Block suspension | 8. Hycomax magnet |

factory would allow the design engineer to miniaturize all the cartridge components.

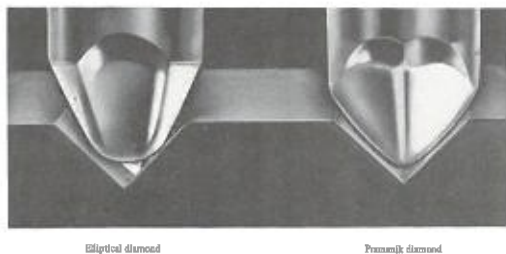
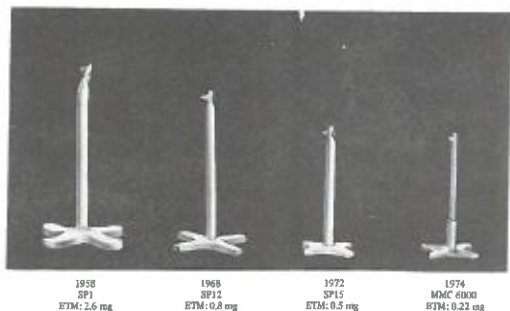
Low Effective Tip Mass

The result was a cartridge in which the most critical component, the stylus assembly, was reduced by 50% in size from previous cartridge models. (See illustration) This, in effect, means that from an effective tip mass of 0.5 mg. in the SP15, effective tip mass was reduced to only 0.22 mg. in the MMC 6000.

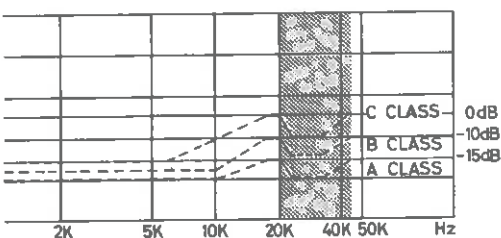
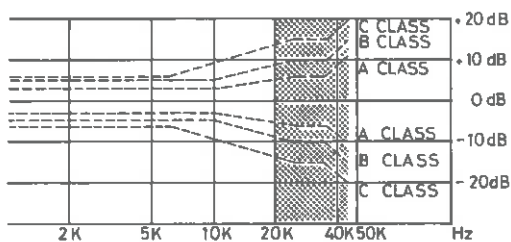
Two other factors contributed to the achievement of this extremely low effective tip mass. One, the low mass cantilever was made of beryllium which is both three times lighter and four times stiffer than commonly used aluminium. The design team found that about 80% of the effective tip mass of the stylus assembly is contributed by the cantilever. Two, the stylus tip of the MMC 6000 is a cone diamond. This means that only the very tip of a conventional naked diamond has been used. Rejecting the shank of the conventional naked diamond reduces the stylus tip mass to less than half that of other styli which use aluminum cantilevers.

The Stylus

The stylus features a new multi-radial diamond, a shape designed by Engineer S. K. Pramanik of Bang & Olufsen. The "Pramanik" diamond has four facets (as opposed to the usual two in bi-radial or elliptical diamonds), each of which are angled to meet only at the edge and not in the middle. The tip of the stylus is flattened so that it cannot touch the bottom of the record groove. The diamond is oriented so that its hardest edge comes in contact with the record. The unique shape enables maximum surface contact on its vertical axis and minimum contact along its horizontal axis.



Total Compatibility



The MMC 6000 plays discrete 4-channel (CD-4), all types of matrix (SQ, QS and RM), stereo and mono discs. The design engineers' idea was to make a no-compromise, stereo cartridge which, because of its wide frequency range (above 45 kHz), would track CD4 records (Quadradsics) faithfully. And a cartridge which, because of its low phase shift in the audio range, would be compatible with all matrix records.

RCA/JVC, joint developers of the CD4 system, have established a system whereby the CD4 capabilities of a cartridge can be evaluated. Their rating system contains four classifications: A, B, C and D; the first three being acceptable and D unacceptable. In the rating system, the cartridge's frequency response (see diagram 1) and its channel separation (diagram 2) are the two important criteria. In both cases, the MMC 6000 has a Class A rating. Finally, the MMC 6000 has a vertical tracking angle of 20° - a value which complies with the new IEC and DIN standards.

Vertical Tracking Force is One Gram

For additional technical data, see specifications.

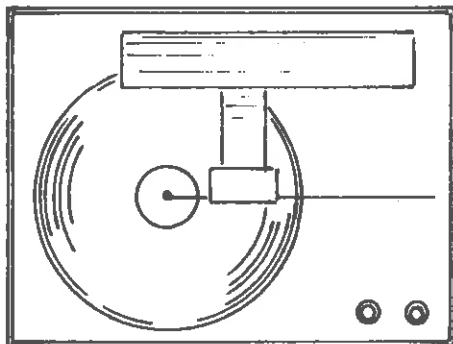
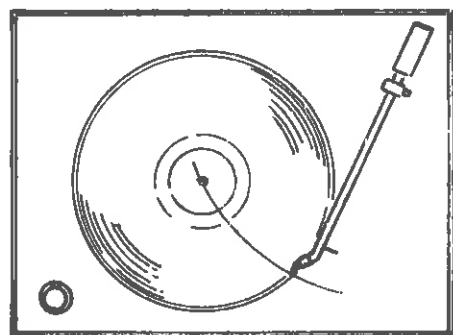
THE TONEARM

Pivoted Arms

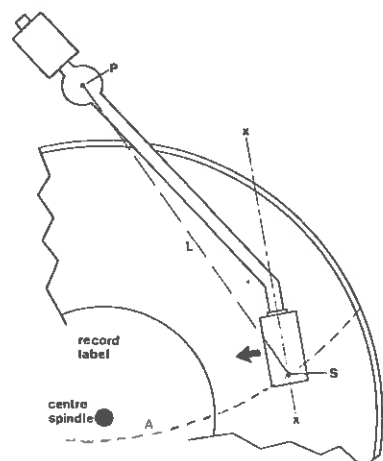
Every time Bang & Olufsen designed a tonearm for a conventional turntable unit, it was necessary to accept the same compromises which other manufacturers must make: a pickup arm that pivots at the rear right-hand corner of the turntable unit and traces an arc as it travels across the record.

The ideal would be to trace the record in a straight line from its edge to its center, keeping an accurate tangential relationship between the stylus and the groove at all points, in the same way as the master record is made.

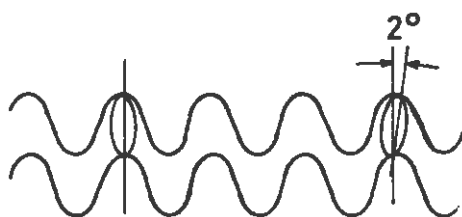
But this ideal path of travel is unattainable when a conventional pivoted arm is used. However a fair approximation can be achieved by compromises in the arm geometry - for example, by positioning the pickup cartridge at an angle to the pickup arm axis and by increasing the arm length. Several configurations have been devised but even in the best, a true tangential relationship between stylus and groove is achieved only at two points (where the arc bisects the tangent). Tracking angle error occurs at every other location. The increased length of the arm also means greater inertia(mass). Increased mass causes greater sluggishness in the movement of the arm. This hampers the use of high compliance pickup cartridges. Playing a record that is not perfectly flat, or small movements in the resilient suspension of the turntable, will cause objectionable distortion of the signals delivered by the pickup.



Recording



Stylus S moves on arc A. Axis X-X is offset from arm. L is effective arm length, from pivot P to stylus tip S. Broad arrow indicates skating force.

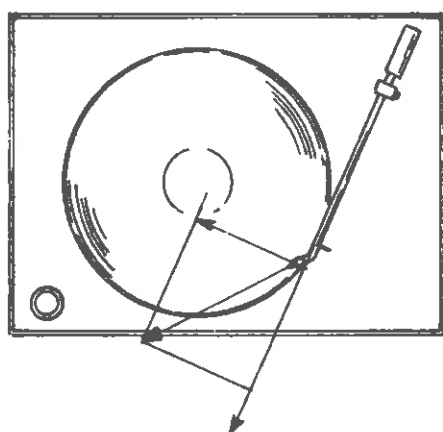
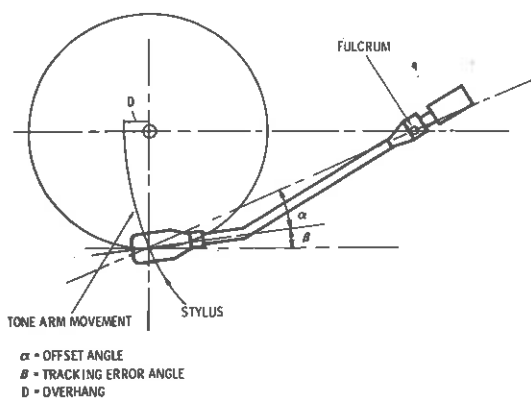


Angular Tracking Errors

As a rule, these can be limited to a maximum of 2° in well-designed tonearms, but as the usable frequency range on records is increased, even a 2° deviation will cause harmonic distortion of high frequencies. Distortion resulting from angular tracking errors exist where the maximum utilizable frequency range is approximately 20 kHz. These problems will be magnified on discrete 4-channel records (Quadradiscs) which require a frequency response up to 45 kHz.

Skating Effect

The geometry of the pivoted arm introduces a force which, unless compensated, will cause the pickup arm to skate towards the center of the record. The



appearance of pickup cartridges with increasingly lower recommended tracking forces accentuates the skating problem. The low tracking force must be distributed evenly on both groove sides. If suitable anti-skating forces are not applied, during its travel the stylus will press harder against the inner groove wall than on the outer. This creates unequal signals from the two sides of the groove and heavier wear on the inner groove. Worst of all, loud passages will throw the stylus out of the groove, thus damaging the record. Optimum compensation is a requirement that is difficult to meet. A host of more or less advanced anti-skating devices have been devised over the years. In fact, such devices are perhaps the most frequent subject of "inventions".

For several years, Bang & Olufsen has designed tonearms with totally integrated skating compensation. This was possible because we were able to optimize the function to cope with one type of pickup and did not, like other manufacturers, enter into serious compromises in order to accommodate the use of different types of pickup cartridges on a given arm.

In order to understand what parameters affect skating force, and hence its compensation, some of the most essential factors will be mentioned here:

- Tonearm length: geometrically determined
- Off-set angle: geometrically determined
- Tracking error: dependent on place on the record
- Speed: 33-1/3 or 45 rpm
- Cutting system: dynagroove, etc.
- Tip diameter at point of contact: elliptical, conical, or the new 4-channel stylus shapes
- Stylus wear: Stylus age
- Record radius at the point where the pickup is on the record.
- Modulation: loud or soft music

Only the first two factors are constant because they are geometrically determined. This means that they are constant for a given turntable unit. But all other parameters are variable, so it is evident that total compensation is not possible.

Since it was the objective of the development team to use a pickup with high compliance and ultra-low tracking force, the considerations relating to tracking error and skating compensation caused a great deal of speculation. However, it soon became obvious that there was only one way to go: to play the record exactly the way it was cut - that is, in a straight line from the edge of the record to the center.

Straight Line Tracking

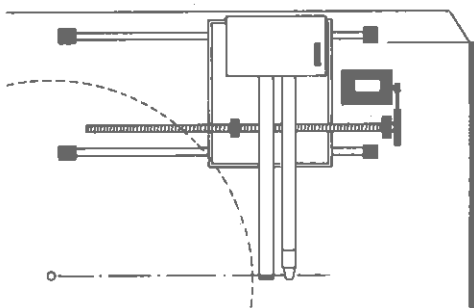
Systems which transport the pickup along a straight line from the edge of the record to its center have been seen before. But they still involved compromises notably in the problem of matching the components.

The requirements of an ideal system can be drawn up as follows:

1. Completely tangential tonearm travel
2. Mechanical connection to chassis only through precision bearings
3. Suspension that eliminates skating force
4. Tonearm control that reduces tracking error
5. Minimum tonearm inertia
6. No mechanical action caused by signal leads
7. No unnecessary groove loading

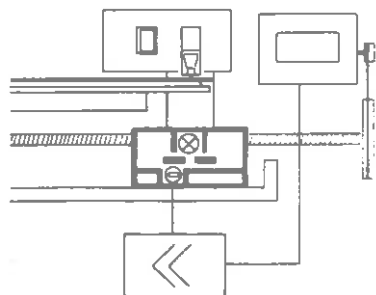
The Ideal Combination: Electronically Guided Tangential Arm

The integrated tonearm on the Beogram 4002 fulfills the above requirements.



Tangential tonearm travel is secured in this way: while the record is being played, a servo motor continuously carries the entire tonearm system, (the pickup and pickup arm, with its horizontal and vertical suspension) towards the center of the record. Using a servo motor for this job means that the groove is not exposed to any unnecessary load whatsoever.

The advantages of this system and how it works will be most easily understood if we begin where the pickup has been lowered into the lead-in groove on the record and has traveled a short distance into the normal grooves. What happens now is that the record makes a revolution and brings the pickup closer to the center by one groove. This displaces the tonearm by a fraction of a degree. In a static position, a shutter mounted to the vertical suspension of the pickup arm will interrupt a beam of light between a lamp and a photo-resistor. (See diagram)



During play, the slight movement of the pickup arm and the shutter (when the turntable platter has made one revolution) causes the photo-resistor to be illuminated as the shutter now no longer interrupts the beam.

When illuminated, the photo-resistor activates the DC motor via an amplifier so the tonearm system is moved inwards until the shutter again interrupts illumination of the photo-resistor. Thus the

horizontal angle of the arm is automatically and continually monitored and corrected so that tracking error is kept to an absolute minimum. Measurements show that the tracking error is never allowed to exceed 0.04° !

Horizontal and Vertical Friction

Movement of the tonearm in the vertical plane is secured by an ultra-low friction bearing using hardened pivots carried by Teflon supports. The horizontal movement is handled by precision ball-bearings in a suspension which was developed in co-operation with the Swedish SKF ball-bearing manufacturing company. The result of this type of precision suspension is horizontal and vertical friction values of 5 - 15 mg measured on the pickup diamond.

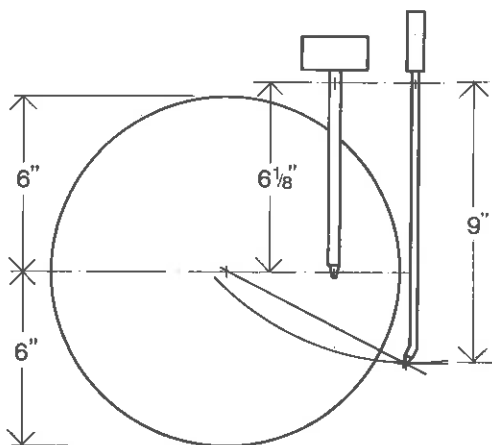
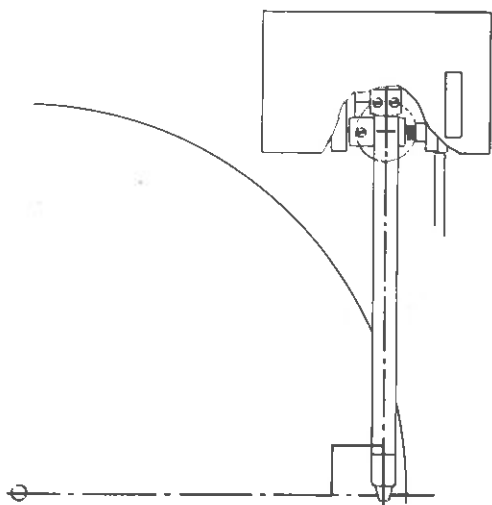
Skating Effect Eliminated

The suspension of the horizontal tonearm movement is accurately placed tangential to the groove into which the pickup is lowered. Skating force is therefore completely eliminated, since the forces which cause skating do not exist in straight line tracking.

The friction between groove and diamond still exists, but because the force now goes straight through the pickup, the pickup arm and its support, a horizontal force does not occur. Consequently the pickup does not track one side of the groove more heavily than the other.

Low Mass Arm

The tangential tonearm system permits the use of a very short tonearm. The length of the tonearm on the Beogram 4002 is only $6\frac{1}{8}$ inches - approximately half the diameter of a 12 inch record. Since the arm is so short, its mass is appreciably lower than that of conventional arms. Made of an aluminum tube, the arm mass is a mere 4.4 grams. In comparison, the mass of a high quality, pivotal arm is about 6.8 grams. (Both without cartridges.) When the cartridge is added, the comparison is even more startling since the plug-in MMC 6000 pickup cartridge (designed especially for the tangential arm on the Beogram 4002) is a mere 4 grams. (The Beogram 4002 will accept no other cartridge but one of the MMC line.) This gives the Beogram 4002 a total pickup arm and cartridge mass of 8.4 grams, whereas the total mass of any other high quality combination currently on the market can be anything between 12 and 15 grams, depending on the cartridge and mounting hardware. The arm is kept in balance, vertically and horizon-



tally, by an adjustable counterweight.

In combination with the MMC 6000 pickup cartridge, the complete tonearm system has an extremely low inertia. This means that warped records and movements which pass through the Beogram 4002's pendulum suspension will not affect the pickup, which operates at a tracking force of only 1 gram.

Adjusting Tracking Force

Tracking force is adjusted by tightening a spring system at the rear of the arm suspension, using a screwdriver. The use of a spring system to produce the necessary tracking force ensures that no unwanted mass is added to the tonearm system.

Raising & Lowering the Arm: The Requirements

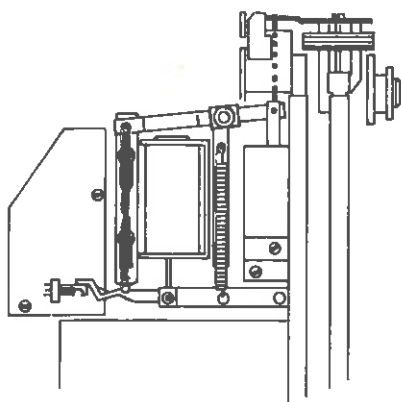
When using a turntable unit it is important to protect the pickup stylus. Lowering the tonearm should therefore be made with a damped movement so that the stylus does not contact the record with too much force. In the event of failure of the power supply to the record player, the tonearm should raise so the pickup stylus will not be damaged when voltage is re-applied, and so that the pickup will not remain resting on the record for any length of time.

Turntable units are normally equipped with a device to damp the lowering of the tonearm. These devices have identical damping action in either direction - that is, both for raising and lowering the tonearm. The force employed for lowering or raising the tonearm is normally obtained from the turntable. This is undesirable if stringent demands are made on the turntable motor to achieve smooth rotation (a minimum of wow) and low noise level. Normally, no provision is made for raising the tonearm when power is cut.

Beogram 4002's Solution

The lowering/raising mechanism on the Beogram 4002 is solenoid operated. This solenoid works in conjunction with a damping cylinder which causes the arm to lower at a carefully selected speed. The tonearm will rise automatically if the power supply is removed, (because the magnet is energized when the arm is lowered).

The functions of the tonearm and the turntable drive system are operated independently, via separate circuits and separate motors.



THE TURNTABLE SYSTEM

Basically, a turntable system consists of a motor and a turntable platter mounted on a chassis in a combination which should fulfill four basic requirements. These requirements are as follows:

1. The turntable should be able to play a record with minimum rumble. That is, rumble must be far below the level of human perception and lower than the lowest frequencies which the amplifier and loudspeakers in the audio system are able to reproduce.
2. The turntable should play a record with minimum wow and flutter.
3. The turntable should rotate at an exact (33-1/3 or 45 rpm) and constant speed.
4. The record should be played without interference from vibrations.

1) A Turntable Should Be Able To Play a Record With Minimum Rumble

a) Suspension

If rumble is caused by relative movement between pickup and record groove, the objective must be to "lock" these two together as strongly as possible, and to remove the generators which create such movement.

Obviously, locking the pickup and record groove together is a physical impossibility. However, if the turntable is connected to the tonearm suspension through a very strong bearing and a heavy sub-chassis, maximum resistance to rumble can be achieved. This is the case with the Beogram 4002.

b) Choice of Motor

The motor and transmission must be considered as the principal generators of rumble since motors cannot easily be made vibrationless in quantity production.

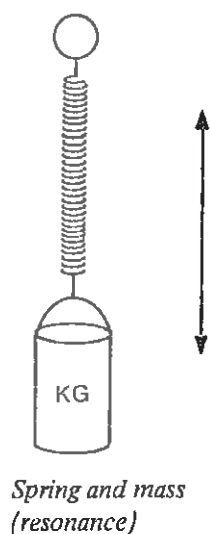
The choice of motor requires a good deal of consideration. Should it be a DC or an AC motor? Should the motor be line-frequency controlled, or controlled by built-in electronic circuitry? Should it be a synchronous or an asynchronous motor? Numerous options exist, but the best transmission is found to be a slow-running, DC tach motor which is controlled by built-in

electronic feedback circuitry. This system can be built to operate at very constant speed. It is possible to switch electronically between two speeds and to adjust either of them to the exact rpm.

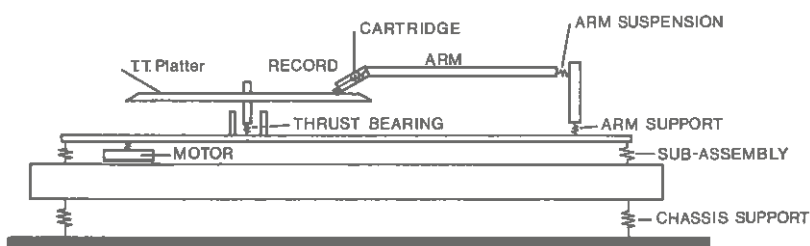
When size and specifications of the motor have been determined, we must decide whether it is to be mounted flexibly or bolted to the chassis. To make this decision, we must consider the problem of resonances.

Resonance

All mechanical systems have inherent resonances. The principle diagram below illustrates the resonant points in a typical gramophone. The objective is to place the resonances so that they do not interact and excite each other.



*Spring and mass
(resonance)*



The most critical resonances are:

- Tonearm resonance
- Chassis-suspension resonance
- Rotation resonance in the turntable

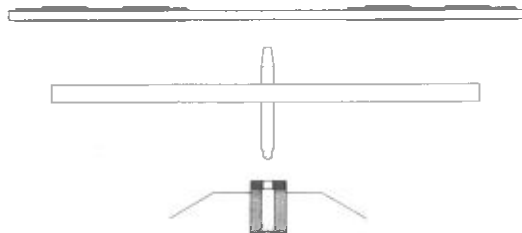
Motor Suspension

The motor selected for the Beogram 4002 operates so quietly that it may be bolted directly to the chassis.

With the motor bolted directly to the outer chassis there are two paths along which vibrations can reach the turntable and pickup. One path is through the chassis and the mountings of the turntable system to the turntable. The other path goes through the motor drive belt to the turntable. A spring suspension of the turntable chassis prevents the passage of vibrations. This spring suspension system has a natural resonance at approximately 4.5 Hz, which ensures that interfering vibrations cannot penetrate to the pickup. There is also the possibility that motor vibrations may travel through the belt drive from the motor to the turntable. The use of a wide, flat, soft rubber belt permits the motor to transmit the required rotatory energy to the turntable, while any vibrations are damped by the elasticity of the belt. Damping is particularly effective in connection with the large flywheel mass of the heavy, dual-casted, non-magnetic turntable. Therefore motor vibrations have no chance of penetrating to the pickup.

The Center Bearing

The other potential source of rumble is the turntable center bearing. If not sufficiently rigid, it can set up vibrations during rotation. For the Beogram 4002 we chose a 12 mm non-magnetic hardened steel shaft with an oil-lubricated sintered bronze bearing and a special thrust bearing. This secures a smooth rotational speed. The heavy shaft, in addition to creating adequate rigidity, ensures that the oil-lubricated bearings will quickly form a load-bearing oil film even after not having been used for some time.



It is because of these numerous design considerations and innovations that the Beogram 4002 has rumble specifications that are barely measurable. In fact, it surpasses the limits of conventional test records and test instruments.

2) A Turntable Should Be Able To Play the Record With Minimum Wow

Wow is undesired frequency fluctuations of the signal from a record. It is primarily caused by uneven turntable rotation.

In the Beogram 4002, wow has been reduced to an unprecedented minimum by consistent use of precision parts: a precision motor; a precision belt pulley; a precision-ground, flat rubber belt; and a well-designed turntable which has been statically and dynamically balanced.

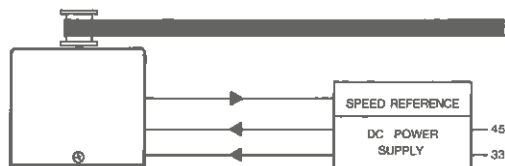
Once these basic factors have been taken care of, other possible sources of wow must be anticipated. The bearing for the vertical tonearm movement must be located in the same plane or nearly in the same plane as the record groove, to avoid "warp wow", which is generated by a warped record.

The resilient mounting of the rotating system is another potential cause of wow. If this resilient system does not adequately filter out irregularities coming from outside sources, these may enter and affect the turntable due to gyro effect and other causes.

The unusual spring suspension used in the Beogram 4002 is described in the section entitled "Pendulum Spring Suspension".

3) Record Must Be Played At a Correct and Stable Speed

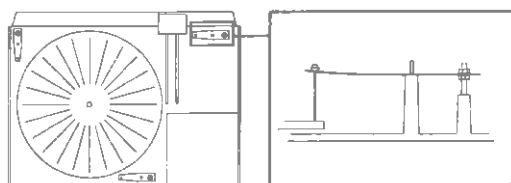
There can be no debating the fact that a record player must be capable of playing the record at the correct speed. And that speed must be constant. It should not vary over a period of time, or as a result of changes in power supply.



The Beogram 4002 uses a drive system, which satisfies these requirements: the drive motor of the tach-DC type, operates on a built-in, highly stable power supply. This ensures accuracy of speed to within a few tenths of a percent. Each speed is individually adjustable within 3%.

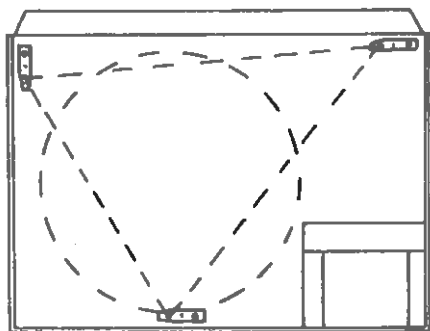
4) The Record Must Be Played Without Interference From Support Vibrations

The trend towards low-weight pickup and tonearm systems and increasingly lower tracking force requires that more careful attention be paid to counteracting support-vibrations in turntable unit design. The pickup should not lose contact with the record groove just because someone is walking on the floor. In other words, the turntable unit should be "traffic-safe". Another factor to be taken into account is the development of the so-called "super-amps". It is entirely understandable that speakers handling that much power can transmit vibrations both through solid materials and directly through the air to the turntable. Our design efforts to remove rumble are also effective against mechanical and acoustical influences on the turntable unit itself.



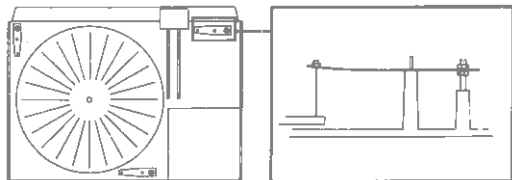
Pendulum Spring Suspension

The turntable chassis has a very low center of gravity and a very large mass. It is suspended from the cabinet by long pendulums, which are attached to adjustable leaf springs. With the mass concentrated at the center of the triangle of suspension, the system is exceedingly stable and well protected against external influences. The suspension has been designed to exhibit very low natural resonance because an analysis of the most commonly occurring interference frequencies has shown that this type of interference occurs down to approximately 5 Hz. It was debated whether the suspension system should be damped by some sort of shock absorbers. But analysis of the audible result of some outside influence shows very clearly that the lower the acceleration to which the turntable chassis is exposed, the greater the ability of the turntable unit to resist outside influences.

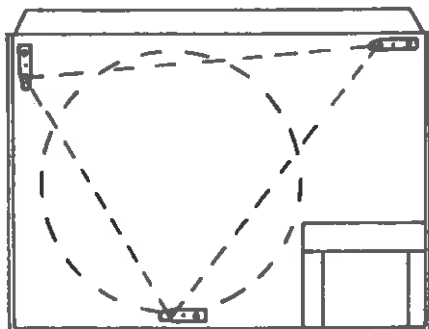


This observation requires some explanation. As a

rule, a pickup arm is adjusted to static balance. If a statically balanced arm receives a shock impulse through its suspension - that is, through the arm bearing - the system is no longer static. It becomes a dynamic system and must therefore be treated accordingly. For such a system to be unaffected by shock impulses, equal amounts of mass inertia must be present on either side of the point of suspension. This cannot be accomplished in practice since the tonearm would then have to be symmetrical on either side of its suspension. (This would produce a rather impractical type of turntable unit). The best result is obtained in systems with counterweights, using short light-weight tonearms and light-weight pickup cartridges. The Beogram 4002, with its advanced tangential system, its short light-weight pickup arm, and its integrated MMC 6000 pickup cartridge represents the height of what is obtainable today.



A special advantage of the pendulum spring suspension is that a horizontal movement, which causes the chassis to vibrate will quickly be converted to a vertical movement within the chassis. The record player itself effectively damps this vertical movement by using the cabinet as an energy absorber.



The pendulum spring suspension of the Beogram 4002 (patent applied for) is the only system capable of converting external forces into movements against which the turntable system has maximum resistance.

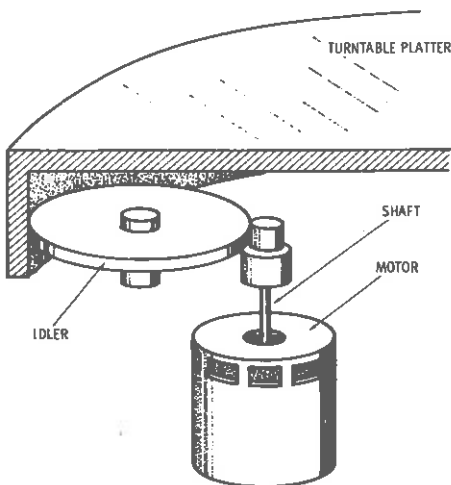
Alternative Drive Systems

During the design phase of the Beogram 4002 major discussions arose regarding the type of drive mechanism which should be employed. Four possibilities were evaluated:

- The Rim-drive
- The Belt-drive
- The Direct-drive
- A combination of Rim and Belt-drive

The Rim-drive

The Rim-drive system was eliminated because, in spite of its low cost, several more important factors weighed against it. Among them: the system's dependence on purely mechanical tolerances for its speed accuracy; additional friction caused by additional suspension (the idler wheel shaft must be suspended in a bearing); a high level of audible rumble which can be produced by wear and deformity in the idler wheel.



Belt-drive Versus Direct-drive

Experiments and long deliberations about the Belt-drive and the Direct-drive systems ensued.

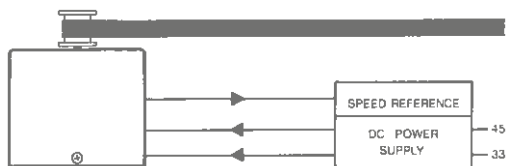
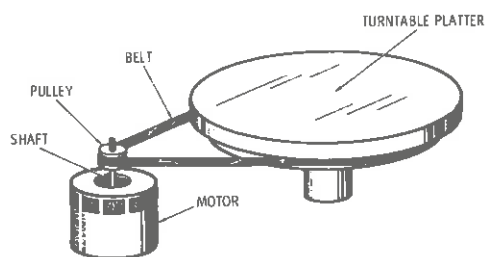
Both systems claimed accurate speeds, low rumble rates and low wow. In principle, the Direct-drive mechanism utilizes a low-speed motor which rotates at the actual required turntable speeds (33-1/3 or 45 rpm). The motor shaft itself is the center of the turntable platter.

In contrast, the Belt-drive system utilizes a rubber belt to transfer power from the motor to the turntable platter. The belt effectively reduces rumble and flutter since the motor vibrations are completely isolated from the platter.

Given two systems which seem to give equal results, although by different methods, Bang & Olufsen choose the Belt-drive system for two reasons.

First, with the use of an accurately ground, flat, soft rubber belt which is resistant to heat, humidity, and oil, the belt-drive mechanism retains its dimensional stability over a long period of use. This contrasts with findings which revealed the tendency of the direct drive bearing to lose its perpendicularity, giving rise to wow and flutter. Once this happens, it would be a rather expensive fault to correct, whereas a stretched drive belt would be relatively easy and inexpensive to replace (the same would apply in the event of a faulty motor).

Second, the fault for which the belt-drive mechanisms are most often criticized that they have difficulty transferring the torque necessary to operate other mechanical functions, does not apply to the Beogram 4002. This is so because the Beogram 4002 employs two separate motors: one to supply power to rotate the turntable platter, and another - a servo-motor - to control the functions of the pickup arm. A very powerful tach-controlled DC motor has been employed solely to drive the turntable mechanism. This provides a high torque level capable of rotating the 5 lb., dual-casted, non-magnetic platter. With its built-in feedback circuit which enables automatic speed reference, the DC motor ensures accurate and constant speed - variation is less than 0.02%. Furthermore, the tach DC motor has a very low current consumption which means smaller heat generation and because of this, greater component reliability. Thus, the total drive system in the Beogram 4002 is designed to yield optimum performance by employing a carefully balanced



integrated mechanism in which power transfer free from audible rumble, and wow and flutter, as well as accurate and constant speeds are obtained.
(See also section on Support Vibrations)

THE AUTOMATIC CONTROL SYSTEM

In order to secure a sufficiently gentle treatment of records it was decided to incorporate an automatic operation system in the Beogram 4002. Previously, automatic gramophones had to be programmed manually with regard to record size, speed selection, etc.

In the Beogram 4002, programming is handled by a small computer unit. Information from various sections of the Beogram 4002 is fed into this unit which registers and compares them. The result is a unique degree of automation and maximum operating convenience.

To operate the Beogram 4002, all you have to do is put a record on the turntable and press the ON button. The Beogram 4002 takes care of the rest. The record will automatically be played at the correct speed and with the highest possible technical quality.

The Detector Arm

A visible example of a source of information for the computer unit is the detector arm, which is parallel to the pickup arm. The detector arm registers whether or not there is a record on the turntable and, if so, the size of that record. From this the computer unit determines the speed at which the record is to be played.

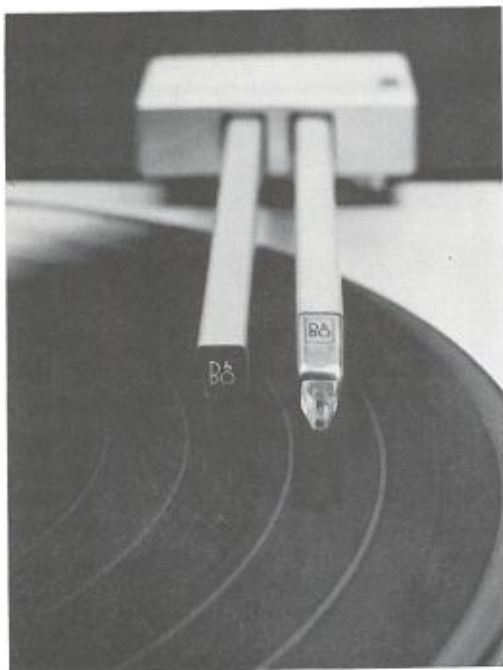
How It Works

(See also "Raising and Lowering the Arm")

A beam of light from a lamp in the detector arm is thrown onto the turntable platter and is reflected to a photocell in the detector arm.

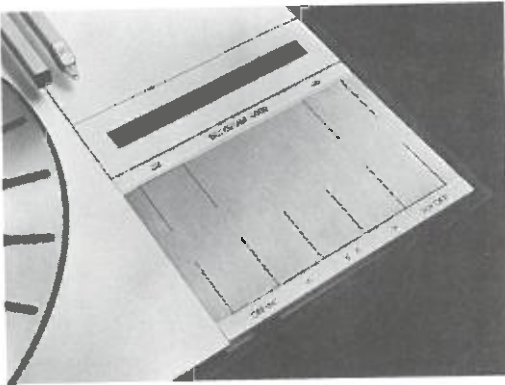
It is the type of reflection received as the arm scans the platter which determines the further action of the pickup arm.

For example, when a 12 inch record is placed on the turntable, the light will be reflected as a continuous beam from the rotating record. This condition causes the detector arm to transmit appropriate information to the control unit which activates the pickup arm and lowers it into the lead-in groove. At the same time, the control unit causes the turntable to rotate at the correct speed of 33-1/3 rpm. The correct speed is established by the fact that there is a big 12 inch record on the platter.



When a 7 inch record is on the turntable, the detector arm scans the platter, receiving a broken beam (an impulse which keeps the arm from lowering) until it encounters the solid black mass of the disc which enables continuous reflections. Again, this condition causes the arm to lower and because of the size of the disc, the turntable automatically starts to rotate at 45 rpm (odd discs, for example a 7 inch 33-1/3 rpm disc, can be cued manually). When there is no disc on the turntable, the detector arm scans the entire platter, and receiving "broken impulses" all the way (regularly pulsating reflections from the ribs on the platter) the arm is instructed to return to its rest position.

POWER ASSISTED MANUAL OPERATION



Automatic operation is not always desirable so the Beogram 4002 is also equipped with power assisted manual operation facilities. It is possible to move the pickup arm in either direction and scan the record at slow or rapid speed. A light touch at the appropriate position on the control panel will lower the pickup arm exactly in the desired groove; another touch will immediately lift the arm for re-cueing elsewhere on the record. (The pickup arm itself is never touched.)

There are also separate speed selectors for each record speed, 45 and 33-1/3 rpm, to assist with stroboscope adjustment and playing odd records (e.g. a 7" 33-1/3 rpm disc).

CD-4 DEMODULATOR

The Beogram 4002 was designed to be compatible and obsolescence-proof. This means that its basic concept is a gramophone which is capable of playing all records - irrespective of the method of their recording.

It is for this reason that the gramophone is fitted with the MMC 6000 pickup cartridge which plays CD-4 (Quadrads) , all matrix, stereo and mono discs. A plug-in CD-4 demodulator is available. It can be fitted quickly and easily by a technician. Space is provided inside the turntable cabinet. Once fitted with the CD-4 demodulator, the Beogram 4002, will automatically reproduce the 4-channel information recorded in Quadrads.

COMPONENT INTEGRATION

Many of today's fine quality turntables make it possible for the consumer to select not only the cartridge and stylus which he prefers, but also the tonearm itself. In fact, many audiophiles prefer this arrangement. They believe that with a number of alternatives available, they can best determine which tonearm, cartridge, and stylus will provide the best performance for them.

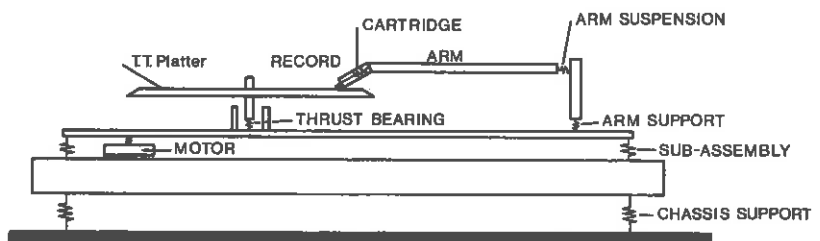
These alternatives are not available with the Beogram 4002.

The fact is that buying a cartridge from one manufacturer, a tonearm from another and a turntable from yet another, involves compromises and possibilities for mismatching which the serious music lover should not accept.

Take, for example, the cartridge and tonearm combination whose mass/compliance interaction affects the system's ability to cope with common-place record warping (and which records are completely flat today?); record wear problems; and the question of platter and arm suspension.

The design of any high fidelity component involves a series of compromises. Those who designed and engineered the Beogram 4002, preferred to minimize the compromises which must normally be made for a turntable. For example, when one does not know which cartridge will be used with the turntable, the designer is forced to compromise by making provisions for a wide variety of cartridges. But by integrating the tonearm and the MMC 6000 pickup cartridge into a single, finely balanced, functional system, Bang & Olufsen has been able to minimize these compromises.

One of the greatest sources of distortion in a gramophone is resonance. Since all mechanical systems have inherent resonances, the objective must be to place the resonances so they do not interact and excite each other, thus causing distortion. The diagram below illustrates the resonant points in a typical gramophone. It is clear that the chances of isolating such resonances in a turntable unit assembled under non-laboratory



conditions are minimal when compared with a unit which is totally integrated.

The integration of the component parts of the Beogram 4002 enables a precise matching of each system and an isolation of the resonant frequencies of each integral part.

The independent, resilient suspension of the platter and tonearm effectively isolates the system from external resonances.

In short, total integration enabled Bang & Olufsen engineers to achieve greater overall performance with the Beogram 4002.

The ease with which the turntable is operated is a point in case. As is the product's harmonious appearance.

And fundamental to it all are two features which we call Domesticity and Authenticity. We design our products to create music, not confusion. Music - simple and effortlessly, and with integrity.

TECHNICAL SPECIFICATIONS

The Turntable Unit: Beogram 4002, type 5513

Tracking error: electronically compensated,
maximum 0.04°
Skating error: eliminated by tangential (straight-
line) tracking
Tonearm mass: 4.4 grams (8.4 grams with cartridge)
Pickup cartridge: MMC 6000
Lift: electronic air-pressure damped
Drive system: belt
Motor: tach-controlled DC motor
Fine speed adjustment: ± 3%
Speeds: 33-1/3 - 45 rpm, electronic selection
Wow and flutter: less than 0.025%
Rumble: More than 65dB
Suspension: pendulum and leaf springs
Dimensions: 4" x 19½" x 15"

The Pickup Cartridge: MMC 6000

Stylus: naked Pramanik diamond
Radius of curvature: Horizontal contact 7 microns
Vertical contact: 50 microns
Frequency response: 20-15,000 Hz ± 1.5dB
30-45,000 Hz RCA/JVC class A rating
Channel separation: better than 25dB at 1000 Hz
better than 20dB at 500-10,000 Hz
better than 15dB at 30,000 Hz
Compliance: 30 x 10⁻⁶ cm/dyne
Channel difference: less than 1.5dB
Effective tip mass: 0.22 milligrams
Tracking range: 0.7-1.5 grams, 1.0 gram
recommended for normal use
Output: 0.6mV/cm/sec. 3.0 mV for average music record
Load: 100 Kohms/100pF
Vertical tracking angle: 20° (new IEC and DIN standard)
Weight: 4 grams

Subject to change without notice

REVIEWS TO DATE

The Beogram 4002

1. Hi-Fi Stereo Buyers Guide, Winter 1974
2. Performing Arts, December 1974
3. High Fidelity, January 1975
4. FM Guide, August, 1975
5. Stereo Review, October 1975

The MMC 6000 Pickup Cartridge
(An integral part of the Beogram 4002)

1. Stereo Review, September 1974
2. High Fidelity, December 1974
3. Hi-Fi Stereo Buyers Guide, January-February 1975

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