FROM THE DEPARTMENT OF ORTHOPAEDICS OF THE CAROLINE INSTITUTE (CHIEF: PROFESSOR STEN FRIBERG) AND THE KING GUSTAF V RESEARCH INSTITUTE (CHIEF: PROFESSOR N. SVARTZ)

THE USE OF SOME ELECTRIC MEASUREMENTS ON BIOMECHANICAL PHENOMENA

By

CARL HIRSCH, M.D.

INTRODUCTION

New methods of measurement have, during the past years, been tested experimentally at our laboratory in the study of deformation of lumbar intervertebral discs. The preliminary results of the work done hitherto have been presented (Hirsch-Nachemson, 1954, and Hirsch, 1955). The technical equipment used was partly described in the same publication.

The experience accumulated indicates that our measuring instruments permit us to establish with a considerable degree of accuracy certain fundamental physical properties, on which it would appear that practical clinical thinking can be based.

Several institutions, I am happy to note, have shown interest in this technique of measurement. The time therefore seems ripe for a report of the use of the measuring instruments in question.

The present paper is based solely on technical considerations, and practical orthopaedic problems have therefore not been taken into account. It thus has little to offer to those whose interests are purely clinical.

INSTRUMENTS

A displacement pick-up (Philips GM 5537) is connected to a measuring bridge (Philips GM 5536). To the bridge is connected an amplifier (GM 4531), from which a cable is drawn to a pen recorder (Kelvin and Hughes Type II A).

The displacement pick-up consists of an inductive displacement pick-up, constructed in principle so that a core of loss-proof material is moved in a field of three coils. The primary coil is fed by a carrier wave, and, in accordance with the transformer principle, a voltage,

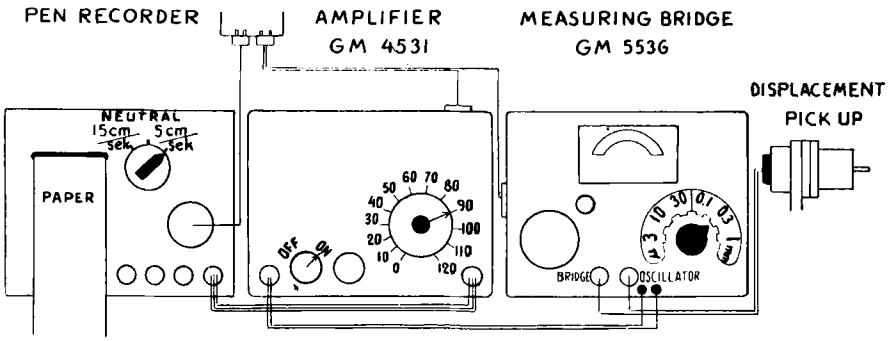

Fig. 1.

which depends on the movement of the core of the coil, is induced in the two secondary coils. In this way, the pick-up permits measurement of displacements.

The static-dynamic measuring bridge. The measuring bridge is constructed so that static phenomena can be read off directly from a built-in indicating measurement, or meter, and dynamic phenomena can be recorded on a special recorder. The carrier wave, which is modulated in the transducer, is generated by an oscillator in the measuring bridge. The voltages so obtained are amplified in a built-in amplifier and are connected to the meter or the pen recorder. The mechanical displacement is thus transformed into electric impulses, which can then be amplified.

The amplifier. The purpose of the amplifier is to amplify voltages from the bridge.

The recorder. The recorder registers the impulses obtained from the transducer via the bridge.

The recording system works as follows: A voltage is applied to the pen and, since the paper is lined with a conductive layer, there will be a flash-over, whereupon the movements of the pen will be recorded on the paper by a line. By a special adaptation of the system, the recorder can record phenomena up to 90 cycles per second. The paper is driven forward by a synchronous motor, thus ensuring constant speed of the paper. The latter can be fixed either at 5 cm. per second or 15 cm. per second.

(For further technical data, the reader is referred to the Philips Company in Holland).

TECHNIQUE OF MEASUREMENT

If the probe of the pick-up is placed against the surface whose displacements are to be studied, the displacements of the probe will cause

variations in the current which can be read off both on the meter of the measuring bridge and on the pen recorder. The displacements of the pick-up must be calibrated in relation to the recorder. Calibration is done with the aid of a micrometer screw.

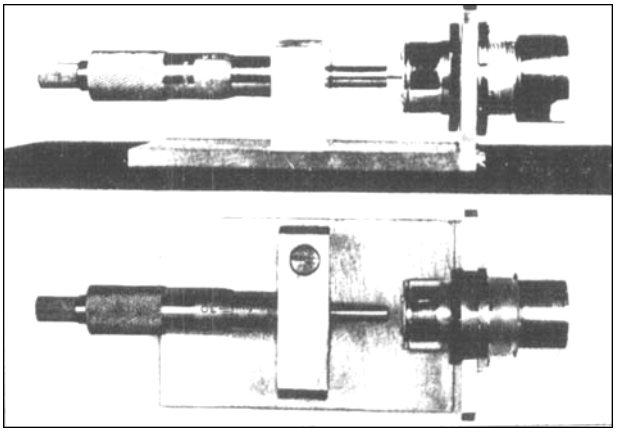

Fig. 2.

ERRORS IN THE USE OF DISPLACEMENT PICK-UPS CONNECTED TO MEASURING BRIDGES AND PEN RECORDERS

The accuracy of the displacements recorded by the pick-up must be evaluated before any conclusions can be drawn from results of experiments. Two absolute requirements must be fulfilled in this respect:

1. Both the specimen and the pick-up must be firmly mounted.
2. All the components of the electric measuring system must be calibrated.

MOUNTING OF THE SPECIMEN

It is essential that the only displacements recorded should be those that occur in the specimen being studied. It should always be borne in mind that extraneous factors may easily influence the pick-up. Such sources of error must be avoided. It is therefore essential that the force applied to the specimen actually reaches it, and that both the specimen and the pick-up be mounted so as to eliminate outside disturbance.
All foreign influences must be analyzed. To do this, different materials,

whose physical properties are known, must first be tested. Vibration-proof mounting can be achieved by using different shock-absorbing materials. But even with these precautions, it is advisable to begin each series of experiments and to complete each day's work with controls on materials the properties of which are known. Control experiments may be made with metal cylinders equipped with strain gauges. It is in this way only that one can be sure that the measurements refer to phenomena in the specimen examined.

CALIBRATION

The whole principle of measurement is based on registration of variations in the induced current supplied by the pick-up. If this is to be translated into accurate values for the displacements in a given material, the various components in the electric system must be stabilized. If several measuring bridges are used simultaneously, which is desirable when displacements in one and the same specimen are to be studied in different sections, all the values recorded must, of course, be compared with one another.

CALIBRATION OF THE PICK-UP

The measuring bridge can be adjusted to varying sensitivity, i.e. the measuring range can be varied as required. At the lowest sensitivity, i.e. 1 mm., a diagram like that in Figure 3 will be obtained. The graph is linear as far as the probe of the pick-up can be moved (2.5 mm).

With the next degree of sensitivity, i.e. 0.3 mm., the calibration curve will run a different course. The linear part will represent scarcely 1.5 mm. of the entire stroke of the probe (Figure 4). This means that the useful measuring range, i.e. a measuring range that will give accurate values for direct readings from the diagram registered by the recorder $\pm$ 0.75 mm., is situated around the middle of the stroke of the pick-up probe. Thus, before the pick-up can begin to record, its probe must be pressed against the specimen to a depth half the length of the stroke. This also means that accurate values can be obtained for only 0.75 mm. on either side of the middle of the stroke. Obviously this restricts the measuring range of the method when greater sensitivity is desired. Tests can then be made only of material, the displacements of which do not exceed 1.5 mm., i.e. 0.75 mm. in each direction. In the case of cartilage, this means that the forces at play must be of such magnitude that the cartilage does not respond

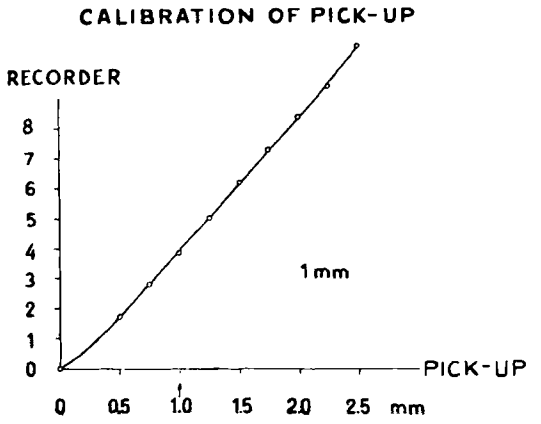

Fig. 3.

with a greater deformation than can be measured. If the recorder gives a greater deflection than can be measured, the experiment will be of no value.

The measuring range decreases in proportion to increases in measuring sensitivity. Figure 5 shows the useful measuring range for "0.1 mm." This is in all scarcely 1 mm., i.e. ± 0.5 mm. on either side of the middle of the stroke of the pick-up probe.

If several pick-ups are used simultaneously, all of them must obviously be calibrated, for the statements above concerning the measuring range cannot be applied generally. Different pick-ups yield different values, as shown in Figure 6. One must select those which react in a uniform manner.

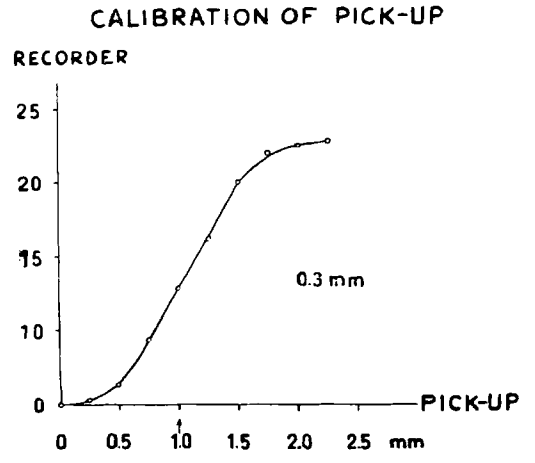

Fig. 4.

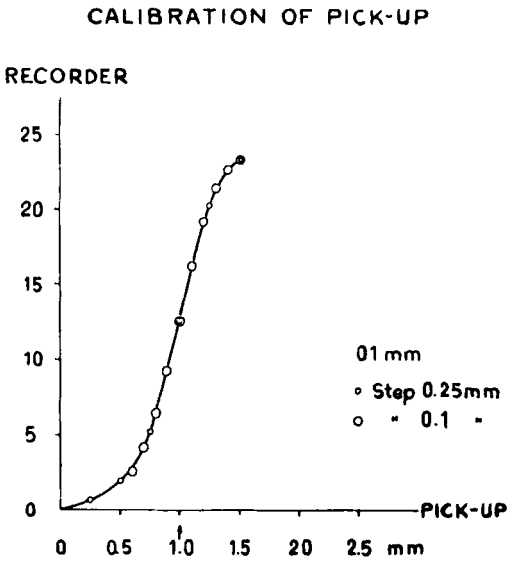

Fig. 5.

The experiments reveal that the measuring bridge can be adjusted to a measuring range that suits the nature of the material under study. At the same time, however, the examiner must determine the range within which the values recorded are dependable.

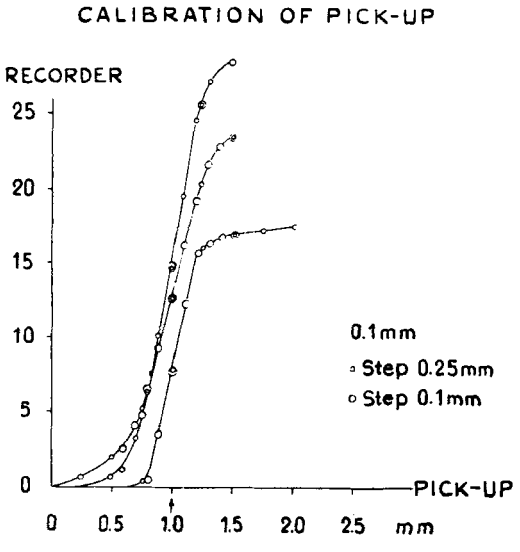

Fig. 6.

CALIBRATION OF THE MEASURING BRIDGE

The different bridges were in turn connected to the same pick-up, amplifier and pen recorder. It was found that one bridge (Fig. 7) differed from the others. This shows the importance of "cross-testing" and also that fatal errors of measurements can creep in unawares.

However, errors of this kind can be eliminated once they have been detected. A specific pick-up must always give the same deflections on the recorder, regardless of the measuring bridge to which it is connected.

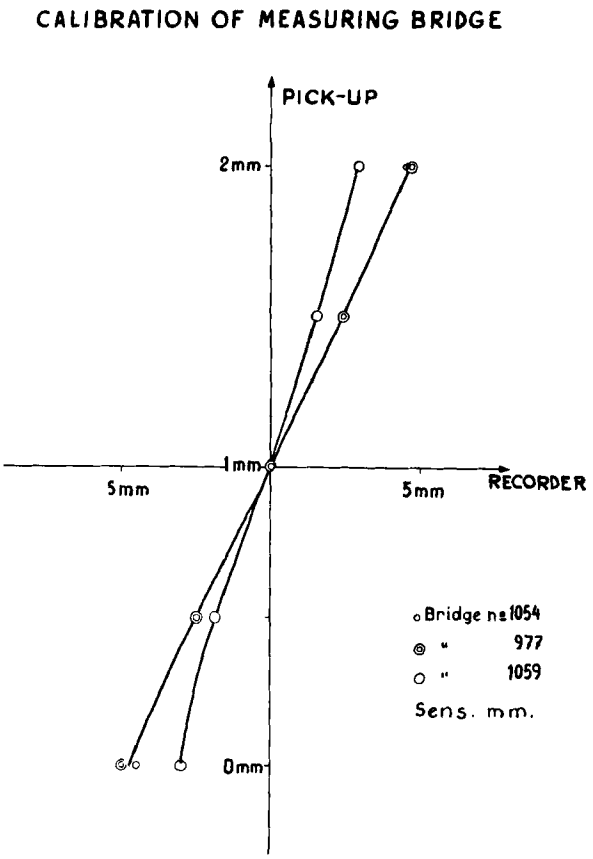

Fig. 7.

CONTROL OF THE AMPLIFIER

The range of amplification of the amplifier is of special interest. The scale on the instruments manufactured by the Philips Company is not sufficiently differentiated to be suitable for biologic material.

Careful testing is required to find the appropriate adjustment. Fig. 8 illustrates how our four amplifiers first led to inaccurate values being recorded, despite the fact that the same amplification according to the scale was used in all cases. This is easily corrected.

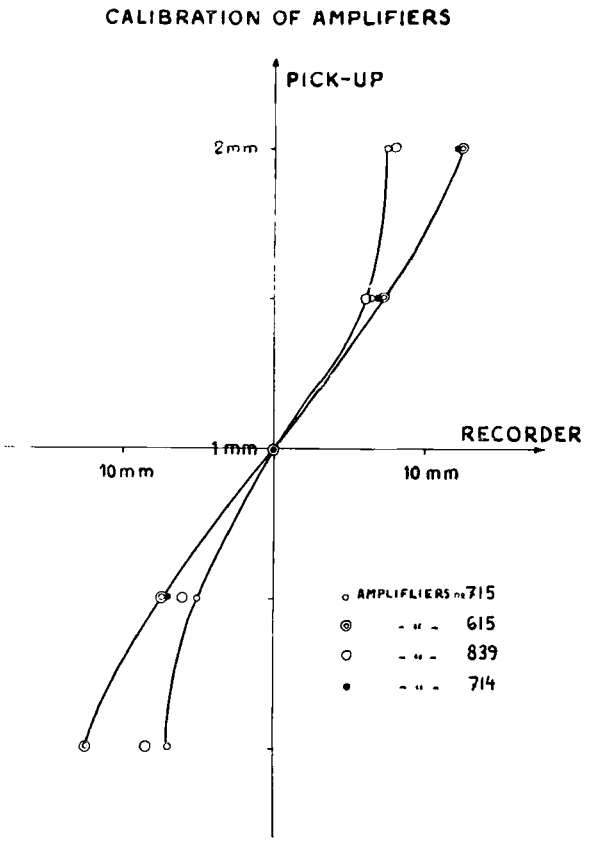

Fig. 8.

CHECKING THE RECORDER

We have no criticism of the pen recorder. Calibration of the pen recorder is shown in Figure 9. Meantime, it should be borne in mind that the recorder cannot record phenomena of more than 90 cycles per second.

ACCURACY OF MEASUREMENT

In view of the sources of error that may arise during the course of the experiments, even though they have already been eliminated once, it is necessary to control the instruments at certain intervals. It should

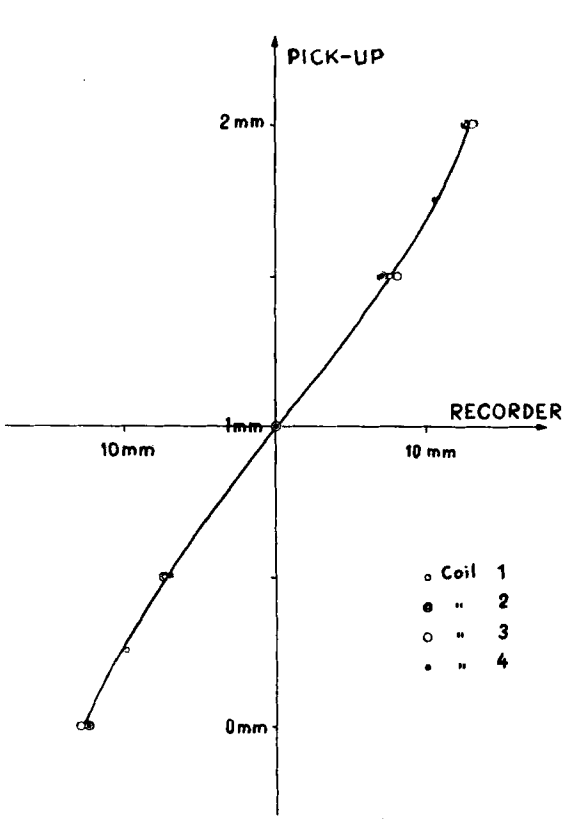

Fig. 9.

also be remembered that the apparatus must be connected for at least half an hour before use. This is to ensure constant temperature in the instruments.

After we succeeded in bringing the abovementioned errors under control, we were able to achieve a high degree of accuracy. Fig. 10 shows an example of the values obtained on simultaneous testing with a micrometer screw at a sensitivity of 0.3 mm. The measuring errors were less than ± 5 per cent.

The purpose of the foregoing report is, on the one hand, to serve as a warning against indiscriminate use of very sensitive measuring instruments and, on the other hand, to show that the method described is, if applied correctly, a significant addition to biomechanical research. It will undoubtedly have a very wide range of use, not least in the mechanics of orthopaedics. It captures and makes clear displacement

phenomena that are invisible to the naked eye because of their great speed. The method might perhaps be called a biomechanical microscope.

SUMMARY

This is a report on technical errors which may occur when inductive displacement pick-ups connected to measuring bridges are used in the study of the mechanical behaviour of certain mesenchymal tissues, mainly intervertebral discs. The object to be tested, as well as the pick-up, must be mounted in such a way as to eliminate extraneous disturbances. The pick-up must be calibrated. The measuring bridge must be tested for electric stability. Amplifiers and pen recorders must be checked. The errors can be controlled, in which case they are less than ± 5 per cent. The instruments described can be regarded as biomechanical microscopes of great importance to investigations on the reaction of joints and spines to various stresses.

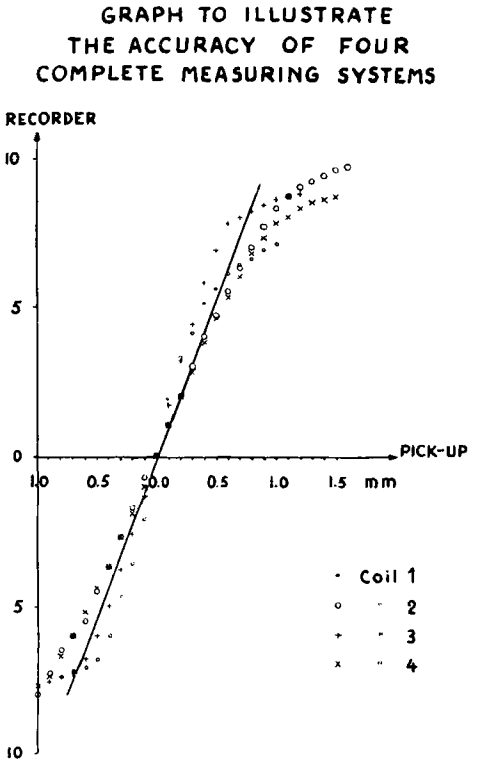

Fig. 10.

RESUME

L'auteur fait un rapport sur les erreurs techniques qui peuvent se produire lorsque des *pick-ups à déplacements inductif embrayés pour mesurer les arcs* sont utilisés dans l'études des fonctions mécaniques de certains tissus mésenchymes, principalement des disques intervertébraux. L'objet à examiner, aussi bien que le pick-up doivent être montés de manière à éliminer les perturbations. Le pick-up doit être calibré. L'arc *scissuré* doit être contrôlé pour stabilité électrique. Les amplificateurs et la plume enregistreuse doivent être contrôlés. Les erreurs peuvent être contrôlées dans les cas où il y a moins de ± 5 p.c. Les instruments décrits peuvent être considérés comme des microscopes biomécaniques d'une grande importance pour les recherches sur les réactions des articulations et de la colonne vertébrale à différentes tensions.

ZUSAMMENFASSUNG

Eine Beschreibung der technischen Irrtumsmöglichkeiten, die auftreten können, wenn man Induktionsregistrierapparate zur Messung von Verschiebungen, die mit Messungsbrücken verbunden sind, zur Untersuchung des mechanischen Verhaltens von gewissen mesenchymalen Geweben, meistenteils Zwischenwirbelscheiben, verwendet. Sowohl das Versuchsobjekt als auch der Registrierapparat müssen derartig aufgesetzt werden, dass äussere Störungen vermieden werden. Der Registrierapparat muss entsprechend eingestellt sein. Die Brücke muss auf elektrische Stabilitet geprüft werden. Verstärker und Schreib-Registrierapparate müssen kontrolliert werden. Die Irrtümer begrenzt werden und betragen dann weniger als 5 ± Procent. Das beschriebene Instrument kann als ein biochemisches Mikroskop betrachtet werden, das von grosser Wichtigkeit in der Untersuchung der Reaktionen von Gelenken und Wirbelsäulen ist.

LITERATURE

Hirsch, C.: The mechanical response of lumbar intervertebral discs. The American Journal of Bone and Joint Surgery 1955. In press.

Hirsch, C. and *Nachemson, A.:* New Observations on the Mechanical Behavior of Lumbar Intervertebral discs. Acta Orthopedica Scandinav. 1954.

Ingelmark, B. E. and *Blomgren, E.:* An Apparatus for the Measurements of Pressure, Especially in Human Joints. Uppsala Läkarförenings Förhandlingar 1948, 1: 75.

Philips Company, Holland: Directions for Use of Displacement and Strain Pick-Up.

Philips Company, Holland: Directions for Use of Direct-Voltage Amplifier.