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CABLE APPLICATIONS IN ROBOT COMPLIANT DEVICES

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Numerous different mechanical/electromechanical compliant devices have been designed in the course of robot developments. These hardware devices, coupled with the software program, greatly influence the overall effectiveness of the robot to acquire the work object and perform simple mechanical tasks. This report describes an engineering model compliant device utilizing cable, as part of the mechanical attachment of a tool to a simulated robot arm. This unique cable system offers a simple inexpensive method to gain a high degree of compliance and permit the acquisition and mate-up of robot held tools with the work object in the presence of misalignment and vibration. Besides illustrating its ability to work with angular and linear misalignments, the report also shows how the compliant cable system can function when both the robot and work object are vibrating. In addition, principles are presented for other larger cable systems, providing much higher force capability for heavier work objects (payloads). This is also true of extreme vibratory motions which can be overcome through the use of a compound compliant cable system shown as a double universal joint.

Another feature illustrated with the engineering model is the principle that the compliant cable device can be adjusted in place to respond in a linear fashion or in an extremely nonlinear fashion. Further, the system can act with little damping or with heavy damping beyond critical damping as desired.

The engineering model compliant device has four Linear Variable Differential Transformers (LVDTs) mounted on it to sense deflection. The output of these sensors, when connected to an oscilloscope, permits remote steering of the robot held device during mate-up with the work object. Further, it is shown that the LVDT signals can be changed into a digital format and handled by either a digital or an analog system:

Figure 1 illustrates the action of the compliant device. The robot is mounted to the lower two bolts and the work object is controlled by the action of a tool mounted to the upper two bolts. Thus the upper two bolts could be mounted to a screw driver, a clamp, a socket wrench, etc. Because the compliant device of Figure 1 can easily move in the six degrees of freedom, it is possible to adjust to the surface of the work object and perform its function. The bending motions of the cable to meet these requirements will be illustrated in the figures that follow.

Figure 2 illustrates the side motion of the compliant cable device. The cable has not only moved in the horizontal plane toward the thumb in the picture but the cable is also rotated because the force is not applied to the center of restraint of the cable system.

Figure 3 is an example of the compliant device under compression. Notice that all of the cables are bending down but none of them are pivoting about the swage points.

Figure 4 illustrates the motion of the compliant device that is activated by a combination of rotational and compression forces.

Figure 5 shows the same compliant device subject to tension forces. The system is so designed that the resistance to compression and tension exhibit the same force deflection curves.

Figure 6 is a close-up macro-picture of the cable in shear. This particular cable is 7 x 7 x 3 IWRC regular lay. It is quite flexible when compared to the common cable used for lifting and fits into small places that regular cable cannot.

Figure 7 is:ure of the bending of 7 x 19 IWRC right regular lay preformed cable severe loading conditions. Notice that the cable handles the loae well with no yielding or falling apart of the cable stranding.

Figure 8 is a:resis curve of a compliant device subject to an ever increasing load.ice the damping which causes an offset in the zero point. Also nothat the stiffness increases as the load increases. This feature of :ompliant device allows a robot to approach a work object softly, buen stiffness is needed for torque or motion, it is there since the :g constant increases with deflection. It is this ability of the cosnt device to get stiffer and stiffer under a load that allows it to t/ery high overloads.

Figures 9a and 9bow a complete hysteresis motion from a strong force on right, 9a, to a :ng force on the left, 9b. The little squares on the compliant device ar(inches each. This device can adjust itself to $\pm 1/2$ inches in every dition. An important factor about these compliant devices is that they: able to adjust themselves to a motion of 1/2 inches in any plane with equ:restraint in all three planes.

Figure 10a and 10b re two pictures of the same configuration where one is stiff, 10a, and oth is quite compliant, 10b. The stiffness curves are shown on Figure 17. Lrge robots can be designed to adjust the compliant attachment in space. 'us the compliant device can be very compliant when it makes contact but chages its stiffness before it starts to work.

Figure 11 is a robot demonstrator to illustrate the points previously discussed. Through various controls on the far side of the demonstrator, the compliant device (so marked and previously described) can move vertically, laterally, in and out and rotate in one plane as indicated on the picture. The cylinder in the foreground is equipped with a bolt and nut facing the compliant device. The compliant device can access the nut and rotate it off the stud. It can further contact and capture the nut, even though the compliant device is misaligned with the bolt and nut assembly. The handle to the right of the aluminum cylinder is used to move the nut back and forth while the socket wrench on the robot's compliant device captures the nut and turns it. This ability of the compliant device to be soft for adjustment and stiff for turning has been previously discussed. The ability of the socket on the end of the compliant device to capture a moving nut is most useful. It should be repeated here that both the robot and work object could be moving in different modes, yet the compliant device will allow the socket to capture the nut.

Figure 12 shows the same robot demonstrator from the top. The nut is clearly shown. The compliant device is shown along with the socket wrench on the end of the compliant device. The rotating controls (operated by hand) are shown on the right. They give the compliant device motion in all three planes while rotating. It should be mentioned here that all of these motions could be controlled with servos if needed.

Figure 13 shows the nut at an angle of 7 1/2° from the line of the robot and the compliant cable device. It is possible with this compliant device to adjust itself to this angle while it rotates and turns the nut up on the bolt.

Figure 14 shows how far a socket wrench can be from the center line of the nut and still grasp the nut and turn it. Figure 14 also shows the LVDT's mounted inside the compliant device to measure the deflections.

Figure 15 shows a close-up of the socket wrench as it is in the process of latching on to the nut (previously shown on Figure 14). Note that the compliant device rotates and translates into a position where it can slide over the nut and turn it.

Figure 16 shows a double compliant device similar to a universal joint in a car. With this device it is possible to meet very large displacements and still not lose the power to operate.

Figure 17 shows the stiff curve of Figure 10a and the very compliant device of Figure 10b. Note the large amount of damping with the soft device and the small amount of damping with the stiff device. As previously discussed, it is possible to adjust the compliant device while operating and change from an extremely flexible device that will adapt itself to large alignments and prevent hard contacts during coupling. When the robot is firmly attached to the work object, the compliant device can be stiffened and respond almost the same as a solid and rigid bar.

SUMMARY

Robotic systems need compliance to connect the robot to the work object. The cable system illustrated here offers compliance for mating but can be changed in space to become quite stiff. Thus the same system can do both tasks, even in environments where the work object or robot are moving at different frequencies and different amplitudes. The adjustment can be made in all six degrees of freedom, translated in or rotated in any plane and still make a good contact and control.

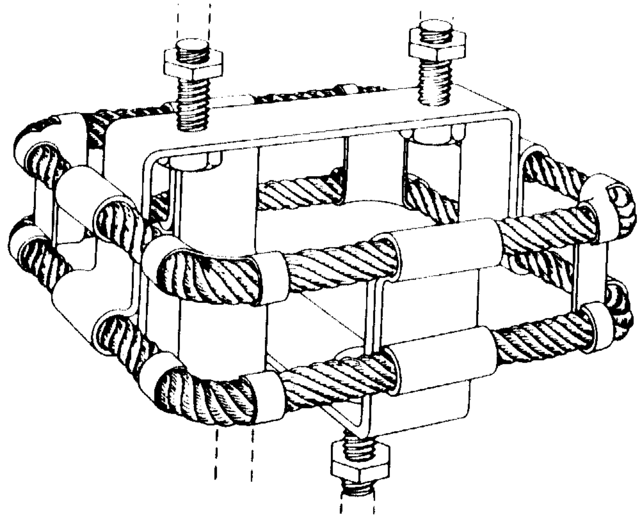


FIG. 1 TYPICAL COMPLIANT DEVICE

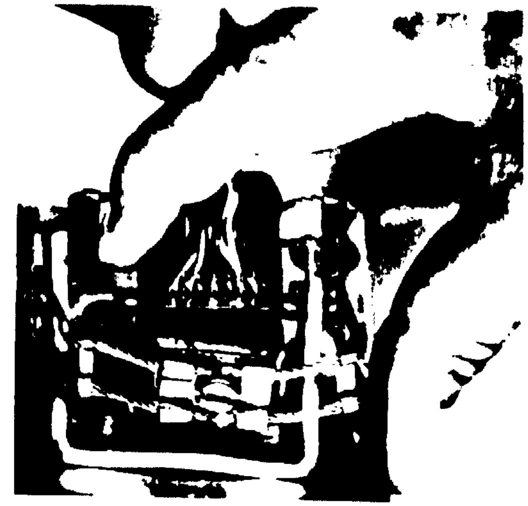


FIG. 2 SIDE MOTION

FIG. 3 COMPRESSION

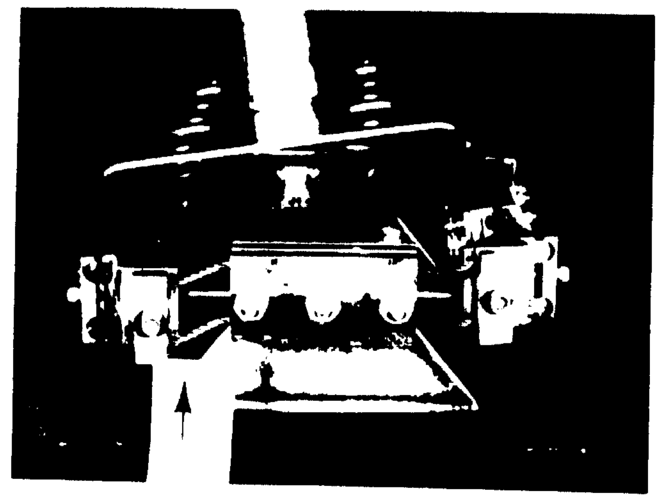
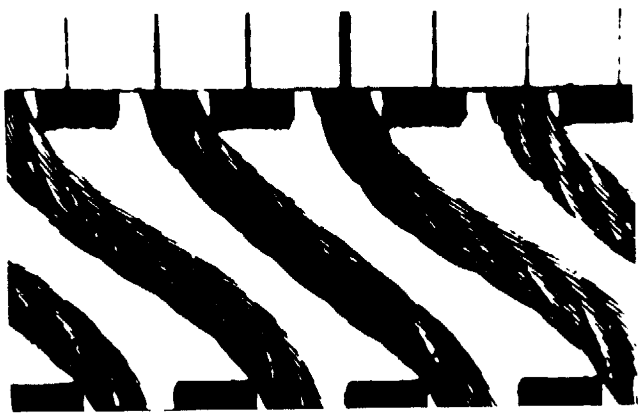


FIG. 4 BENDING

FIG.5 TENSION LOAD



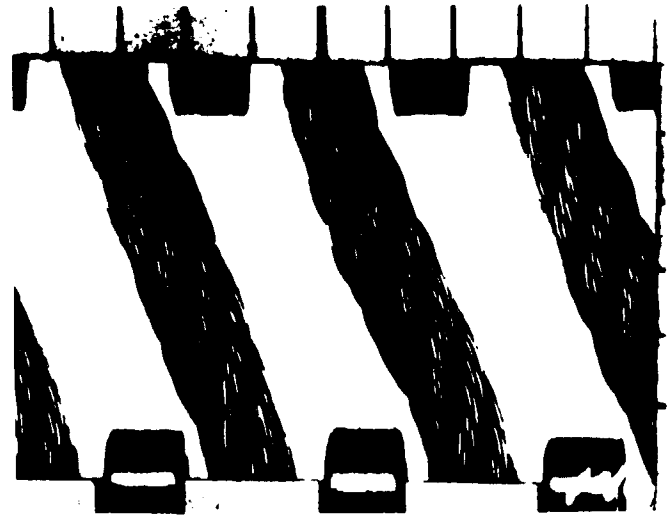
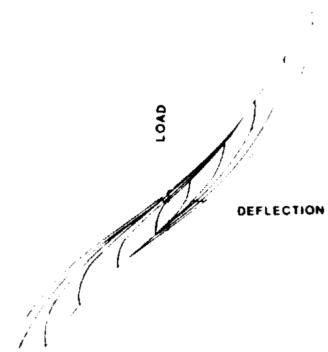


FIG.6 7X7X3 CABLE BENDING



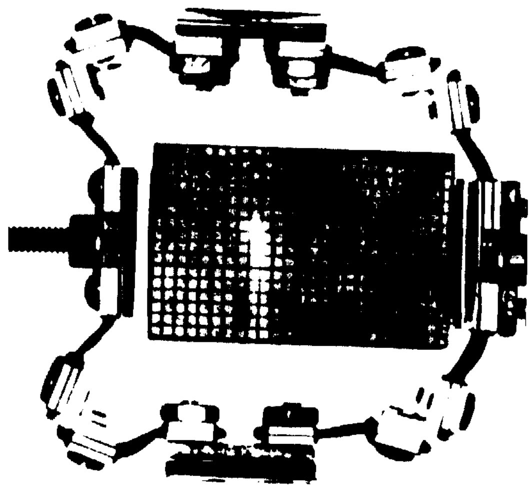


FIG.9-A PULL TO RIGHT

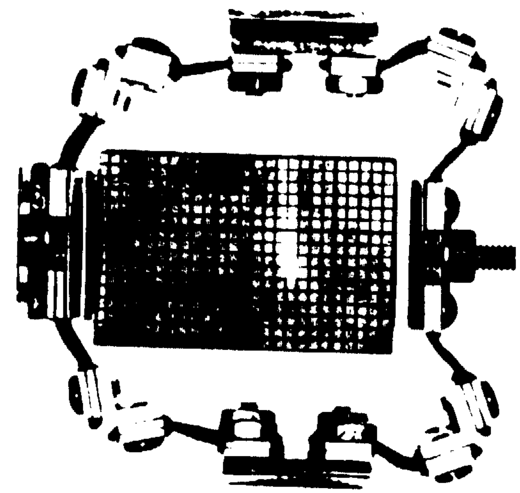


FIG.9-B PULL TO LEFT

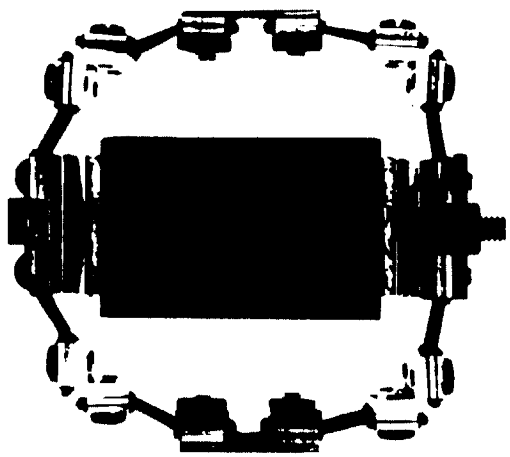


FIG.10-A STIFF CONFIGURATION PULL TO LEFT

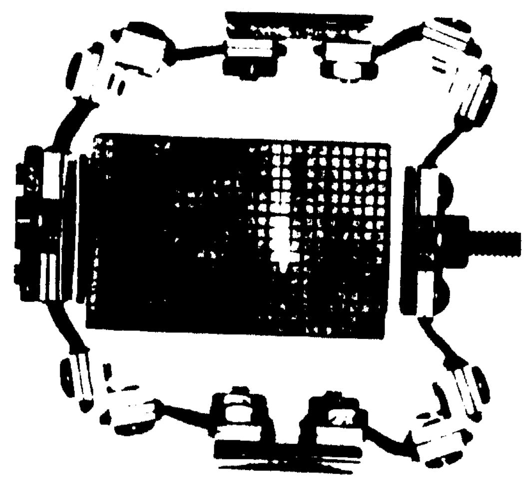


FIG.10-B PLIANT CONFIGURATION PULL TO LEFT

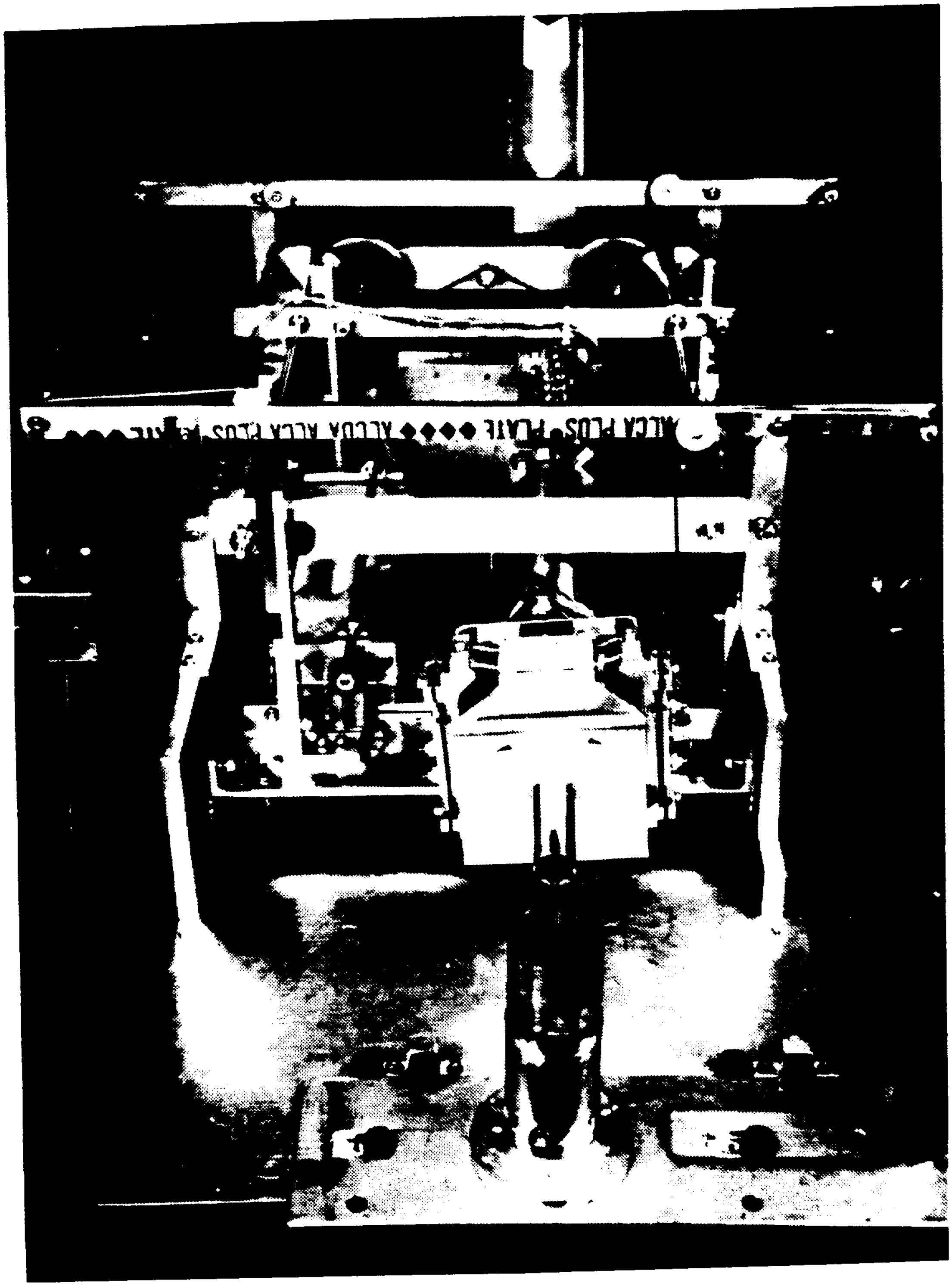


FIG. 11 COMPLIANT TESTING & CALIBRATION MACHINE

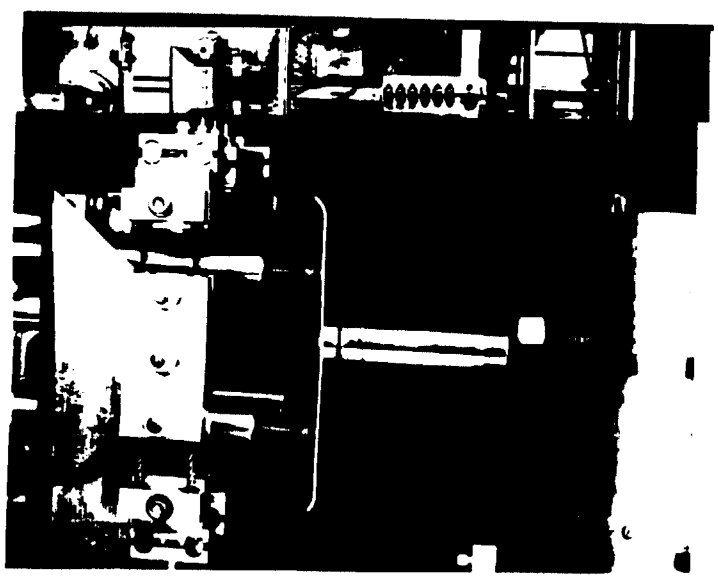


FIG. 14 COMPLIANT DEVICE APPROACHES NUT

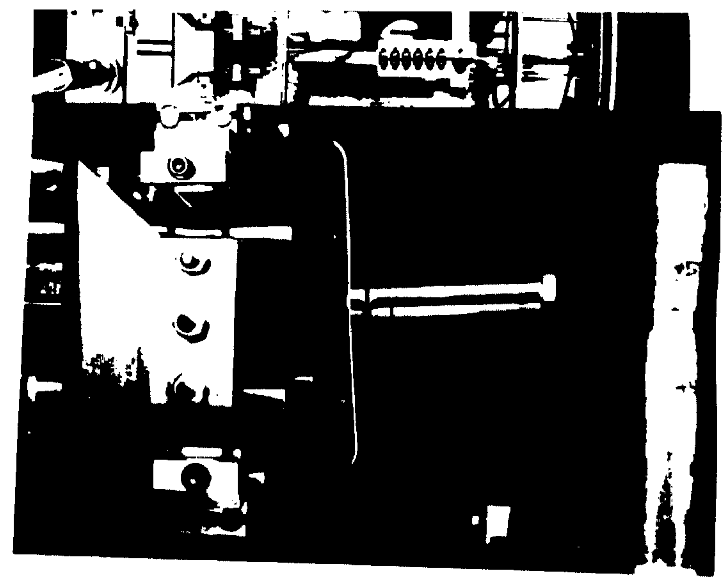


FIG.15 COMPLIANT DEVICE LATCHES ON

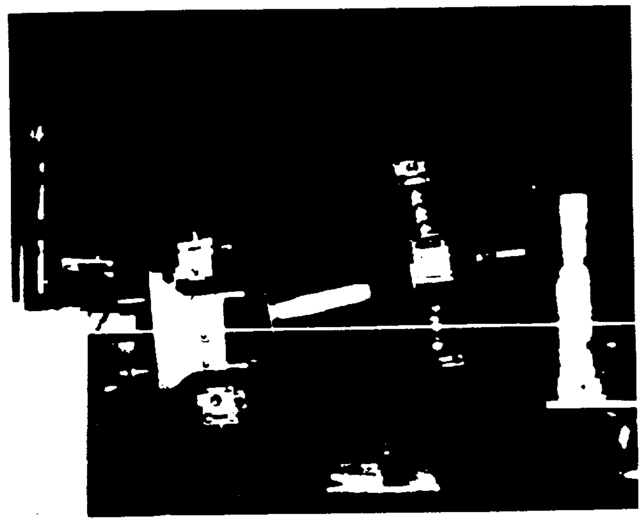


FIG. 16 TWO SECTION UNIVERSAL ACTION

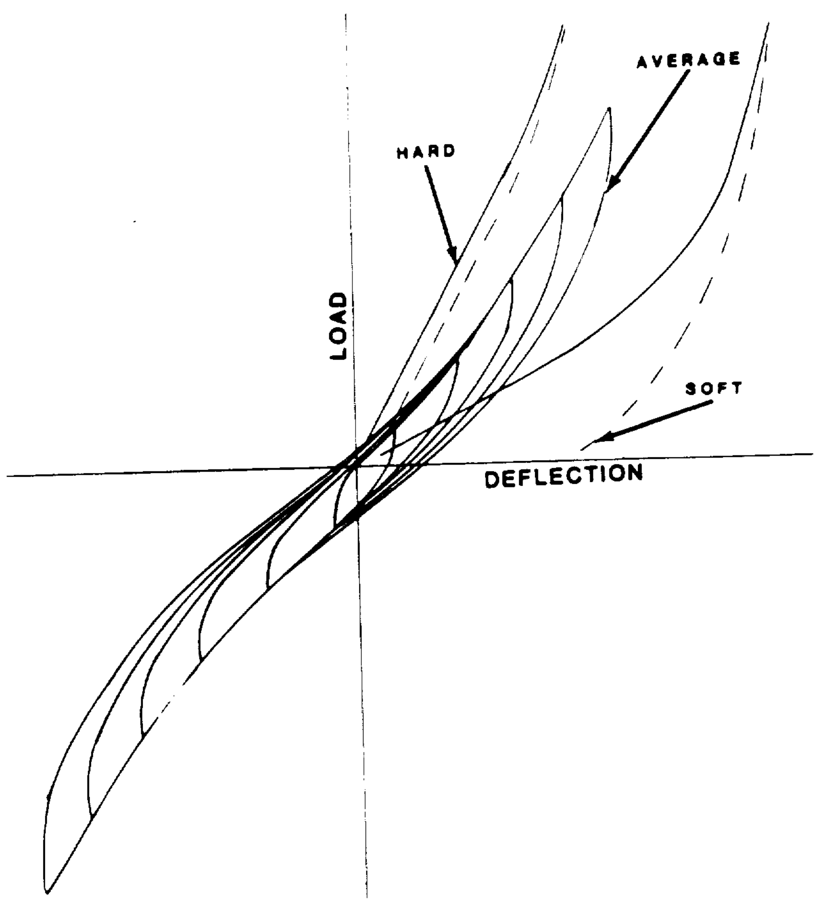


FIG. 17 HYSTERESIS CURVES FOR FIG. 10-A & FIG. 10-B

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