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Cycle Life Machine for AX-5 Space Suit

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ABSTRACT

The need to complete cycle life testing of the new AX-5 space suit joints provided a unique opportunity for mechanism design. To test the joints, a complex series of motions needed to be performed with a high degree of accuracy. According to research on previous space missions, the elbow and knee joints of a suit could see up to 120° of oscillation. These oscillations could occur every second in the elbow and knee joints for approximately 70,000 and 17,000 cycles respectively. Coupled with this movement could be man induced loads of up to 150 lbs. in the elbow and 350 lbs. in the knee which could occur as often as every ten cycles. In trying to design a mechanism to meet these and other criteria, an interesting phenomenon was discovered in the motion of the joint itself. Contrary to what had been expected, as the top of the elbow or knee joint rotated through a fixed arc, the center of rotation of the joint moved several inches both horizontally and vertically. This was discovered after failing to find the center of rotation easily and resorting to using a three-dimensional model of the entire joint on a CAD system. Using the CAD system allowed each joint to be rotated incrementally in space so that the motion could be modeled accurately. Because of the motion discovered, the base of the joint had to be allowed to move as the joint was oscillated and yet be restrained in some manner so that the joint would follow an arc as it rotated on its bearings. The solution was a crank-rocker mechanism. A stepper motor was chosen to obtain the complex motion envelope within the accuracy range required. Using the CAD system again, the crank-rocker mechanism was laid out so that the link connecting the flywheel to the joint produced one oscillation of the joint for each rotation of the flywheel (Figure 1). The base of the joint would be free to move, but would withstand high torques imposed by a lever arm attached to the base of the joint with a small mass suspended from the end. After each ten cycles, an actuator would be activated by a programmable logic controller and a downward force would be applied, taking the slack out of a cable attached to the mass, and applying the necessary man induced loads. The final design performed as expected with no modification required in the mechanism. This project is currently ready for testing to begin.

INTRODUCTION

When the space station is being constructed, an advanced space suit will be needed by astronauts which will be more durable as well as more comfortable. One of two main prototypes for that new suit is the AX-5 space suit developed at NASA-Ames Research Center. One of the main advantages of the AX-5 suit is that it can be pressurized to 8.3 psi, which is twice the pressure of current space suits. Another advantage is its hard aluminum shell which maintains a constant volume, thus making the suit more comfortable to work in since it will not bind. The suit is made up of 15 parts connected mainly by rotary bearings which allow almost a full range of motion. These features provide ease of movement, and the hard shell provides protection from space debris.

The criteria for testing the advanced suits was developed from extensive videotapes of previous space suit use during space shuttle missions, as well as from research done on prototype suits at Johnson Space Center (JSC). According to the data collected, the elbow and knee joints of the advanced suit would see a maximum of 70,720 and 16,474 cycles respectively for a typical mission in space. A joint cycle, as defined by JSC, was 80% of the full range of motion a joint could withstand. For both the elbow and the knee, the full range of motion was 120°. Eighty percent of this motion was therefore 96° in both cases. Coupled with these joint cycles would be man induced loads caused by the astronaut pushing from within the suit, which could occur ten percent of the time. Further research by JSC showed that an astronaut could exert a maximum of 20.8N (150 lbs.) on the elbow and 48.4N (350 lbs.) on the knee. Most of the testing was to be performed with the joint pressurized to 8.3 psi because the internal pressure would effect the movement of the balls inside the rotary bearings; however, after a set number of cycles, the joint was to stop in the vertical position, depressurize, cycle twice, and re-pressurize. The purpose of this depress repress cycle was to model the astronaut entering and exiting the suit.

A cycle life machine needed to be developed to perform testing on both the knee and elbow joints for the cycles and loads specified above. Other important testing criteria the machine needed to meet were to complete one joint cycle in one second, to insure that the joint was within one degree of vertical when the man induced load was applied, and to sequence the test so that a man induced load occurred every ten cycles.

DESIGN

In designing a mechanism to meet these and other criteria, an interesting phenomenon was discovered in the motion of the joint itself. Since the center point of the elbow and knee joint's top bearing surface (Figure 3), shown as the top circular disk, followed an exact circular arc, no problems were expected in designing a mechanism to cycle the joints through an arc of 96° measured from the center of rotation. What was not considered was the fact that the entire top face of the joint would be secured to a bracket, thus the top face created a plane which did not follow any type of fixed arc. This was discovered after failing to find the center of rotation for the joint by inspection and resorting to using a three dimensional CAD (computer aided design) model (Figures 2&3). Each segment of the joint was rotated incrementally through a series of angles, specifically 45°, 90°, 135°, and 180°. Having the multiple views in three dimensions showed that the center of rotation for the top face was indeed moving and that to compensate the base of the joints would have to move several inches both vertically and horizontally in order for the top face of the joint to follow a fixed arc. Figure 3 shows an average center of rotation which was chosen to illustrate the amount the joint would need to move in a typical case. The testing criteria therefore altered so that the 96° would be measured by the amount of inclination of the top surface relative to the base.

Free movement of the base, shown as the bottom circular disk, was an unacceptable solution because there would be no insurance that the rotary bearing in the base of the joint would turn and keep the base of the joint vertical. In order for the joint to be properly tested, the rotary bearing at the base had to be forced to turn rather than be allowed to move out of vertical as the joint cycled because this vertical position was the only way to insure that an arc of 96^{o} had been completed. Several designs for controlling the position of the base were discussed before it was decided that a long tube with a small weight attached to the end would greatly increase the torque the joint would have to overcome to move out of vertical (Figure 1). The weight was only one pound in order to not load the joint. This rod-weight combination was used in conjunction with a guide (not shown in Figure 1) which inhibited horizontal movement as well as movement out of the plane. The end of the rod-weight combination was then connected to a flexible steel cable with enough slack to allow the necessary range of motion. After ten joint cycles, the joint stopped in the vertical position and an air cylinder attached to the opposite end of the cable would remove the cable slack, applying the necessary load.

Design of the mechanism to oscillate the joint went through a similar design process. Oscillation, although it could have been accomplished by continual reversals with a stepper motor or AC motor, was not used because of the extreme wear on the motor from the constant reversals of direction occurring every second, the overhung load and the inherent fatigue of the mechanical components being compounded by the high speed and complete reversal of the inertial weight. In order to avoid these problems, a mechanism which used purely rotational motion from a motor was decided upon. Using a crank-rocker mechanism became an obvious choice after deciding upon rotational motion. A crank-rocker four bar linkage mechanism depends on the relative lengths of each of the links to determine its range of motion. Using the CAD system once again, several linkage configurations were tried until the exact configuration to give an arc sweep of 96^{o} on the output link was determined with no singularities. This method was extremely visual and helped convey the concept of the design to the customer. Also, the effect of changing any one parameter could instantly be seen in the overall design. Once the layout of the linkages was known, the physical appearance and design of each of the linkages was developed (Figure 1). The most critical linkage, the bracket to which the joint attached, was designed in double shear and gusseted to prevent any flexure of the bracket when the man induced load of 48.4N (350 lbs.) was applied.

PNEUMATIC AND ELECTRICAL CONTROL DESIGN

The man induced load was just one part of the pneumatic control system (Figure 4) that had to be developed for the cycle life machine. The sequence began with the joint being pressurized, cycling ten times, stopping in the vertical position for a man induced load, and continuing with this routine for 16 sets of cycles. After 16 sets, the joint had to depressurize, cycle twice, re-pressurize, and continue with the original sequence. This entire sequencing needed to continue until the required number of test cycles were completed. During normal operation, air would flow continually into the joint through a flow meter, which also greatly constricted the flow. During the depress/repress cycle, this flow meter would increase the length of the test by a factor of ten or more and was unacceptable; therefore, the flow meter needed to be bypassed so that the joint could be rapidly depressurized and re-pressurized. This was solved pneumatically by using two three-way valves rather than the obvious choice of one four-way valve (Figure 4). The first valve controlled whether air was received from the source or vented to the atmosphere. The second valve controlled whether the flow went through the flow meter or around the flow meter. This allowed depressurization and re-pressurization of the suit in less than two seconds.

Most of the components of the pneumatic system were determined by the needs of the electrical control system. To insure the integrity of the test, each step of the cycle had to be verified in some manner. Most of this was accomplished through the use of pressure switches which served as flags to the control system. For instance, the joint would not continue cycling if a certain pressure was not reached within the joint or if the cylinder pressure was not fully released on one side of the piston and fully activated on the other.

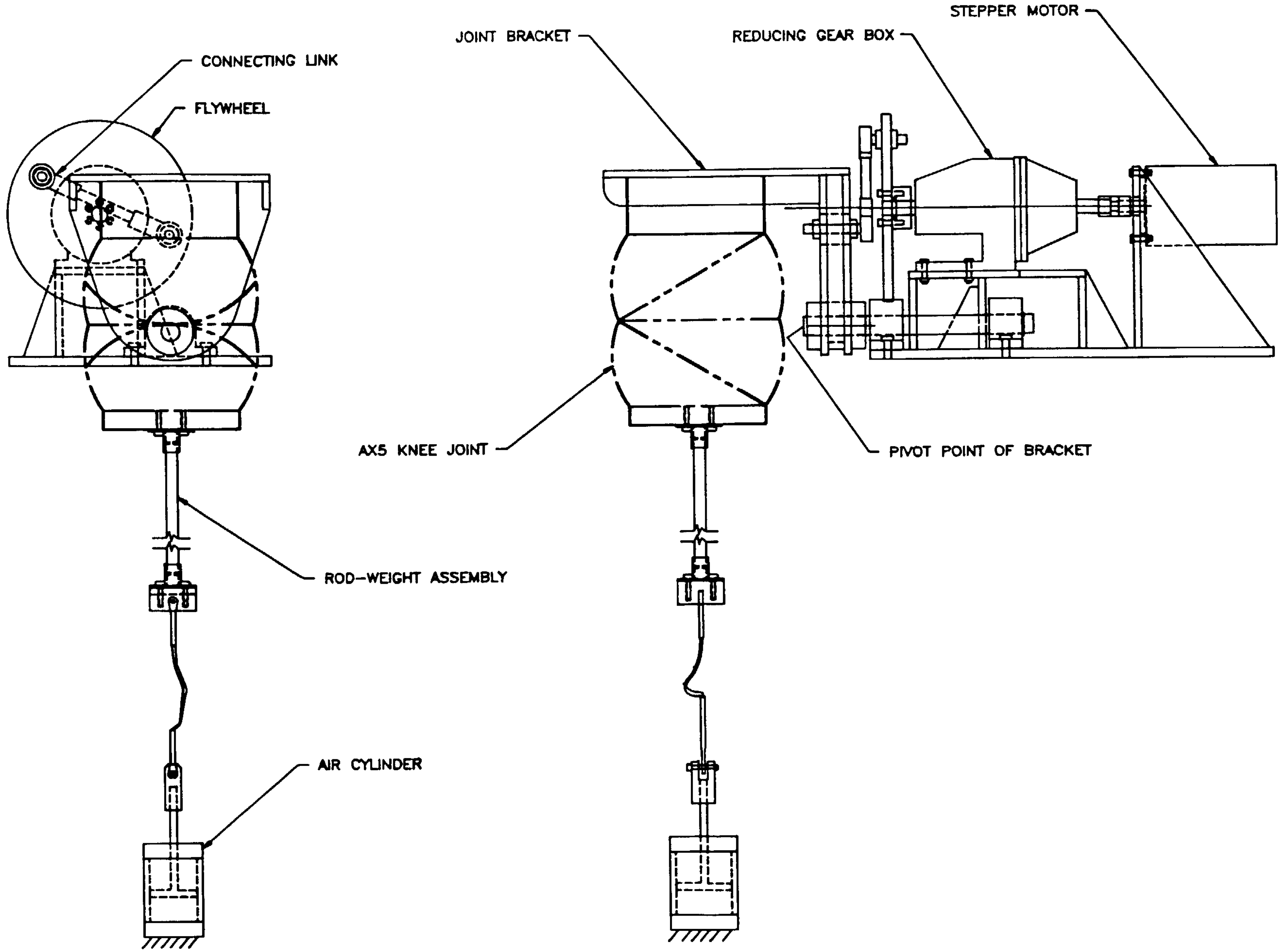
In order to control all of these criteria and still use the stepper motor and indexer for position control, the indexer was integrated with a PLC (programmable logic controller) which controlled and operated all of the peripheral hardware, such as the solenoid valves and pressure switches. The communication between these devices was accomplished using software provided with the PLC.

CONCLUSIONS

In order to accurately test the AX-5 space suit a complex series of motions needed to be performed which provided a unique opportunity for mechanism design. The cycle life machine design showed how three dimensional computer images can enhance mechanical design as well as help in visualizing mechanisms before manufacturing them. In the early stages of the design, potential problems in the motion of the joint and in the four bar linkage system were resolved using CAD. Since these problems would have been very difficult and tedious to solve on a drawing board, they would probably not have been addressed prior to fabrication, thus limiting the final design or requiring design modification after fabrication.

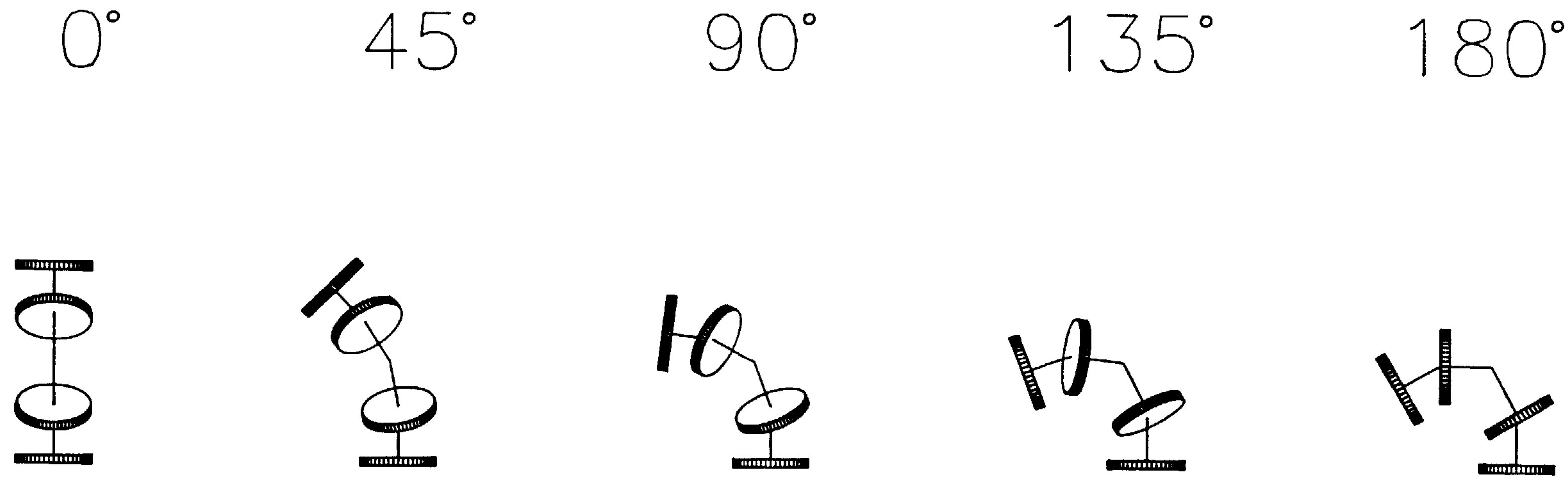
PROJECT STATUS

The AX-5 Space Suit Cycle Life Machine is currently manufactured, installed, and preliminarily testing has begun. Testing is expected to last for one month.



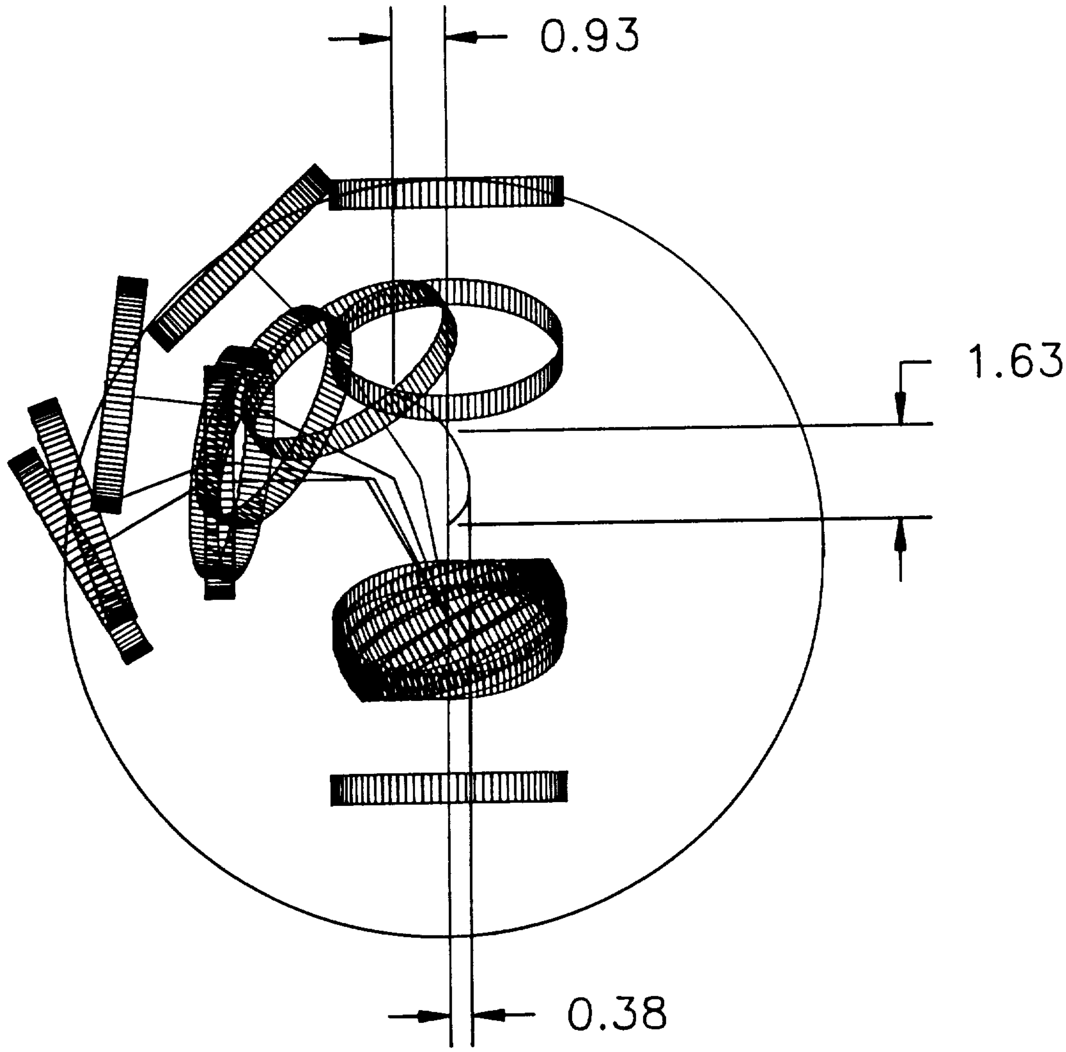
AX5 SPACE SUIT CYCLE LIFE MACHINE ASSEMBLY DRAWING

FIGURE 1



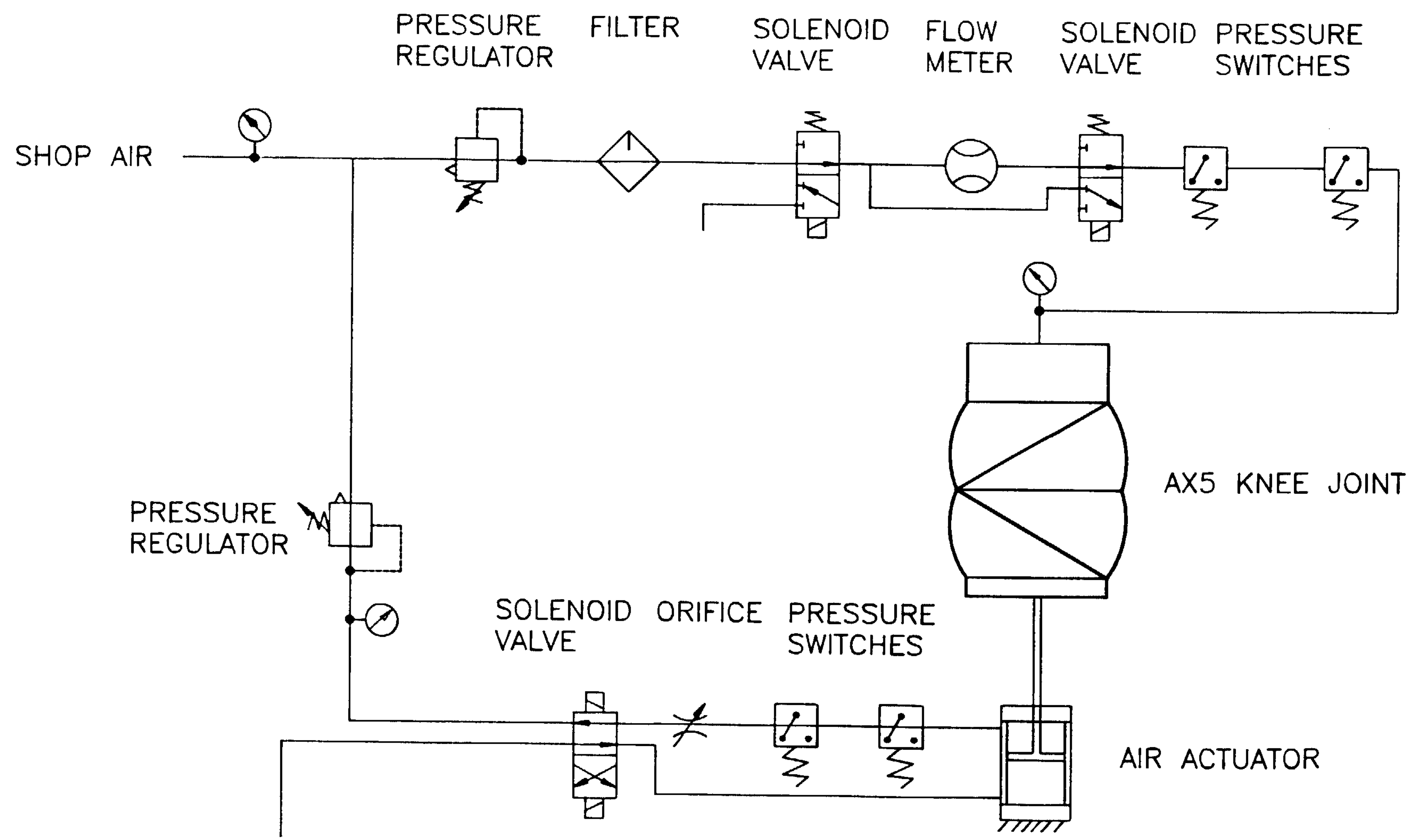
THREE-DIMENSIONAL MODEL OF AX5 ELBOW JOINT

FIGURE 2



OVERLAY OF SEVERAL ANGLES
OF ROTATION SHOWING MOTION
OF AX5 SPACE SUIT KNEE JOINT

FIGURE 3



AX5 SPACE SUIT PNEUMATIC CONTROL DIAGRAM

FIGURE 4