THE PROTO-TYPE
WRIST JOINT ASSEMBLY
TACPAW
[TRIPLE AXIS COMMON PIVOT ARM WRIST]

PHASE II

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FINAL REPORT

BY

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PRINCIPAL INVESTIGATOR

CONTRACT: NAS8-31897 NOVEMBER 1978

UNIVERSITY OF NEBRASKA

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The Proto-Type

Wrist Joint Assembly

TACPAW

[Triple Axis Common Pivot Arm Wrist]

Phase II

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NAS8-31897

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TRIPLE AXIS WRIST — Dwight Johnston (left), EE01, examines a prototype TACPAW delivered to the Marshall Center on Aug. 1 by Dr. Leendert Kersten (right) of the University of Nebraska. The device is ready for integration with a seven-degree-of-freedom protoflight manipulator.

NASA Photo by Bob Thornton

Acknowledgement

This report is a result of contract NAS8-31897, Phase II, to build a proto-type TACPAW (Triple Axis Common Pivot Arm Wrist) which is an electro-mechanical wrist to function with a PFMA and/or ESAM manipulator arm for the Marshall Space Flight Center at Huntsville, Alabama.

The magnificent help of Mr. Galen Neal, undergraduate assistant is gratefully appreciated; furthermore my thanks to Mr. Lyle Ang, shop director in our department, for his assistance and technical contributions; to Ms Louise Simmons for the preparation of this document, to Ms Adeline Nolde for the ordering of the many component parts, to Prof. G. M. Smith, Chairman of the Department of Engineering Mechanics for the allowance of the required release time and especially to Mr. J. D. Johnston (formerly EC-25 and now EE-01) of the Marshall Space Flight Center and the National Aeronautics and Space Administration for this contract and their confidence.

Leendert Kersten

I. Documentation of Component Parts

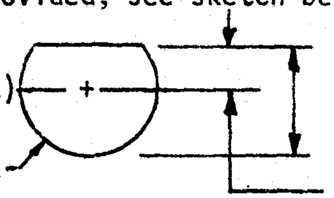
The prototype TACPAW has been built according to the drawings and criteria established in Phase I of the contract NAS8-31897 with minor changes to facilitate fabrication and/or assembly of components. Wherever possible, space approved material was used to allow for the minimum of refurbishing costs in the event a flight proto-type were to be made. The following is a listing of the components and their source as well as specifications.

1. Brakes

Purchased from: Delevan Division - American Precision Industries Inc. (3 required)

Model: (Pancake Reverse Brake) PRB-14-2 special
The special comes from the fact that a smaller shaft needed to be provided; see sketch below:

(also WCD-75, phase I report)



Technical Data:

Torque-Static @ 0 V.D.C	24 oz.in. min.
Coil Voltage D.C	24 std.
Resistance ± 10% @ 25°C	85 Ω
Response time - static electrical	15 m sec. max @ 28 V.D.C.
Drag torque - energized	0.25 oz.in. max.
Inertia (calc.) in. lb.sec^2	8.2×10^{-6}
End play-energized	.001 max. w/8 oz. rev. load
Radial play	.001 max. w/8 oz. rev. load
Dielectric strength	500 V.A.C. - 60Hz - 1 min.
Insulation resistance	500 Megohms min. @ 500 V.D.C.
Weight	4.0 ozs max.

Finish: magnetic mat'ls treated for corrosion resistance

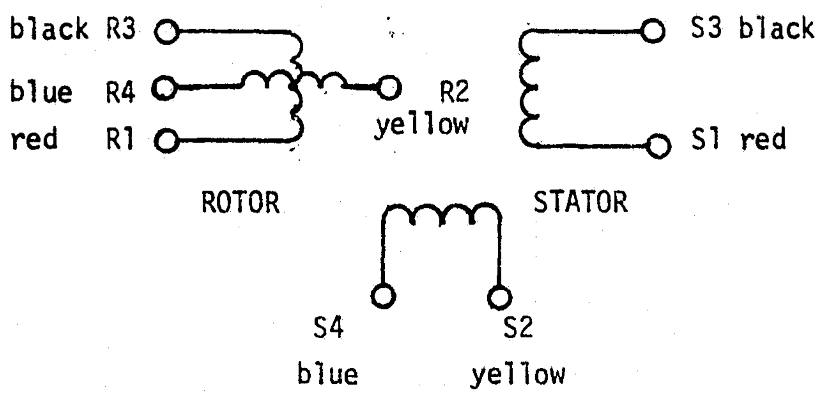
2. Resolvers

Supplier: Singer-Kearfott Division

Model: High Accuracy Data transmission type RX

Part Nr: 3R982-004 size 11 (3 required)

Input Voltage - frequency	26 V.D.C. - 400 Hz.
Input Current	176 m Amp max.
Input Impedance - output open circuit	170 Ω/77°
Output Impedance - input open circuit	42 Ω/80.5°
Output voltage	11.8 V.D.C.
Sensitivity, mV/degree	206
Phase shift	8°
Max. error from E.Z.	3 min.
Friction @ 25°C	6 gm cm
Rotor moment of inertia	2 gm cm^2
Weight	4.0 oz. max.



3. <u>Motors</u>

a) For the yaw motion: (1 required)
Supplier: CADON Technical Sales, Raytown, Missouri
Make: Inland Motor Corporation
Model: T-2719 Direct Torquer - 97 oz. in peak torque
Specifications:

Peak Torque	97 oz. in
Power input, stalled at 25°C	37 watts
No load speed, theoretical @ 31.2 V.D.C.	55 rad/sec
Electrical time constant	0.77 m.sec
Static friction	4.3 oz. in.
Max. winding temp.	105°C
Temp. rise/watt	5.0°C/watt
Rotor inertia	0.022 oz. in. sec^2
Voltage, stalled @ peak torque	31.2 V.D.C.
Peak current	1.2 amp
Resistance @ 25°C	26Ω
Weight	15 oz. max.

b) For the pitch and roll motions: (=2 required)
Supplier: CADON Technical Sales, Raytown, Missouri
Make: Inland Motor Corporation
Model: T-3910 Direct Torquer - 1.0 lb.ft peak torque
Specifications:

Peak Torque	1.0 lb. ft
Power Input, stalled @ 25°C	50 watts
No load speed, theoretical @ 34.6 V.D.C.	36 rad/sec
Electrical time constant	0.84 m. sec
Static friction	0.042 lb. ft
Max. winding temp.	105°C
Temp. rise/watt	5.9°C/watt
Rotor inertia lb. ft. sec^2	3.4×10^{-4}
Voltage, stalled @ peak torque	34.6 V.D.C.
Peak Current	1.42 amp
Resistance @ 25°C	24.4Ω
Weight	1.1 lb

4. Tach Generators

For all three motions = 3 required.

Supplier: CADON Technical Sales, Raytown, Missouri

Make: Inland Motor Corporation

Model: TG-1312 frameless tachometer generator

Specifications:

Voltage sensitivity ± 10%	0.118 volts/rad/sec
Max. operating speed	63 rad/sec
Volt @ max. operating speed	7.45 V.D.C.
Load resistance, min.	4 KΩ
Friction	1.0 oz. in.
Rotor moment of inertia	oz. in. sec^2
Weight	5.0 oz.

5. Rotation Twist Capsules

To provide the minimum of wire looping in the yaw and pitch modes, two (2) identical Poly-twist (slipring type) devices were incorporated. Since these units usually are custom-made, and to keep the cost at an absolute minimum, the supplier was asked for 'shelf-items' which could be used. Therefore, the identified sliprings below should not be regarded as the desired units; they are only suitable substitutes.

Supplier: Poly-Scientific, Division - Litton; Blacksburg, Virginia.

Model: BN 2002 - Twist Capsule

Specifications:

Number of circuits	42
Lead wire size	#26 AWG stranded
Current, max	0.8 amp
Rotation limit	±110° from nullpoint

6. Slipring (roll motion)

Depending upon the functional requirements of the end-effector, a different slipring from the one indicated below may be necessary. Here a total of 21 circuit transmission through the roll mode was selected, again due to availability of a 'shelf' item.

Supplier: Poly Scientific Division - Litton; Blacksburg, Virginia

Model: ET2604 Slip Ring Capsule

Specifications:

Number of circuits	21
Lead wire size	#28 AWG stranded
Torque, starting	45 gm. cm
Input Voltage	6 V.D.C.
Input Current	50 m. Amp
Peak Noise, (across circuit pairs)	15 Milliohms max.

7. Connectors (for small number of pins)

Connectors were provided on each electrical component in order to facilitate repair and removal of a component when needed. To reduce cost, these connectors were soldered in our own laboratory-shop and are therefore custom made, according to the required number of pins at each junction.

Supplier: Scott Electronics, Lincoln, Nebr.
Make: TRW Cinch Connectors - Dura-Con
Specifications:

		parts number	req.
number of contacts	5	CSA1-5P6E2-18.0	10
P = Pin	5	CSA1-5S6E2-18.0	10
S = Socket	10	CSA1-10P6E2-18.0	4
(the large strips were	10	CSA1-10S6E2-18.0	4
cut to size for each	15	CSA1-15P6E2-18.0	2
individual application)	15	CSA1-15S6E2-18.0	2
Wire size	18" - #26 AWG stranded		
Wire insulation	Type E, yellow		
Contacts	24 gauge copper alloy, gold plated		
Insulator mat'l.	Glass-filled Polyester 94V-0.		
Center-center distance	0.050		

8. <u>Connectors</u> (for large number of pins)
Supplier: Hall Mark Electronix, Texas
Make: ITT Cannon plugs

Model:		
	MDM - 15 PH001 B	4 req.
	MDM - 15 SS B	4
	MDM - 9 PH001 B	3
	MDM - 9 SH001 B	3
	MDB1 - 21 SSB	1
	MDB1 - 21 PH001 B	1
	MDB1 - 21 PSB	8
	MDB1 - 51 SH001 B	2
	MDB1 - 51 PH001 B	2

9. <u>Shielding</u>
Signal conductors as well as some power conductors were placed in shielding to prevent cross-talk and/or noise transmission.
Supplier: Scott Electronics, Lincoln, Nebr.
Make: Belden
Type: #8653 tube shielding for 2 leads; woven
#8674 tube shielding for 1 lead; woven

10. <u>Miscellaneous Electrical</u>
Supplier: Scott Electronics, Lincoln, Nebr.

shrinkable tape	TYT-100
shrinkable tubing	FIT-105-1/16
clamps	PLC1M-S4-CP cable clamps

11. <u>Gears</u> (Starred items (*) indicate a change from original)
a) Supplier: Camdale Precision, Michigan
Dwg Nr: WCD-106 (see Phase I report)*
WCD-306 (see Phase I report)

b) Supplier: Winfred M. Berg, Inc, Long Island, N. Y.
(The drawing numbers refer to the Phase I report)

Dwg Nr:		
	WCD-100	WCD-101
	WCD-102	WCD-103*
	WCD-104	WCD-129*
	WCD-201*	WCD-202

WCD-203	WCD-204
WCD-205	WCD-206
WCD-207	WCD-208
WCD-220	WCD-221
WCD-301*	WCD-302
WCD-303	WCD-304
WCD-305	WCD-320

also stock items, such as

M72N-9-S-C-Q12	bevel gears
C64S18-48	spur gear
C48S18-36	spur gear
P48S26-28	spur gear
PE3-8	shaft extension
AP48KS-48-Q10	spur gear
CG1-31	5/16 in. hub clamp
CG3-1	1/8 in. hub clamp
CG3-5	1/4 in. hub clamp
Q2-25	ext. retaining ring
SQ-6	mount cleats
SQ-9	mount cleats
SQ-11	mount cleats
CP5-20	roll pins
CP5-27	roll pins
CP5-17	roll pins
SV-8	wave spring washer
B5-4	prec. thrust bearing

12. Miscellaneous Hardware

Supplier: PIC Design Corp.

Items: L3-1 motor mount cleats
L3-3 motor mount cleats
L3-6 motor mount cleats

13. Bearings

a) Supplier: Keene Corp. Muskegon, Michigan
Kaydon Bearing Division

Model: KA040XP5 (2 for yaw mode)
KA045XP5 (3 for roll mode)

b) Supplier: Precision Bearing Co., Lincoln, Nebr.

Make: Fafnir (for pitch rotation)
Type: MD541 DDFS464 precision

Make: New Hampshire (all internal bearings)
Type: SFR 188LL3 class 7
0.5 in. OD; 0.25 in. ID
SFR 6LL4D class 7
0.875 OD; 0.375 ID

Make: Barden
Type: SS18F. These were substitutes for the SFR 188LL3 above when the total ordered could not be filled.

14. Machined Parts

Supplier: Garner Industries, Lincoln, Nebr.

Drawing Nr: All carry the WCD letters in front of the following numbers and refer to the phase I report. A starred (*) number indicates a change on the drawing; see also revised drawings in back of this report.

70	171*(omit)	180	181
242*	380		
42	140*	143*	144*
150	151	153*	154
159*	160*	161*	344*
380*	395		
141	142*	240*	241*
260*	340	341	342*
343*			

II. Wiring Diagram

To facilitate future testing of this prototype and/or an actual flight prototype, the wiring diagram as shown on the following page and later in the attached drawings (WPD-1-E thru WPD-7-E) was developed. The separation of signal and power harnesses as they enter the TACPAW configuration are compatible with the connectors to the wrist of the PFMA manipulator currently at MSFC in Huntsville, Alabama.

The routing of the wiring through the wrist assembly, was also in two major groupings, the signal and power group. Wherever possible, shielding around paired leads was provided to minimize noise and prevent transmission of false signals. The photographs of the actual assembly also illustrate the compactness of the wiring and the routing of the various leads.

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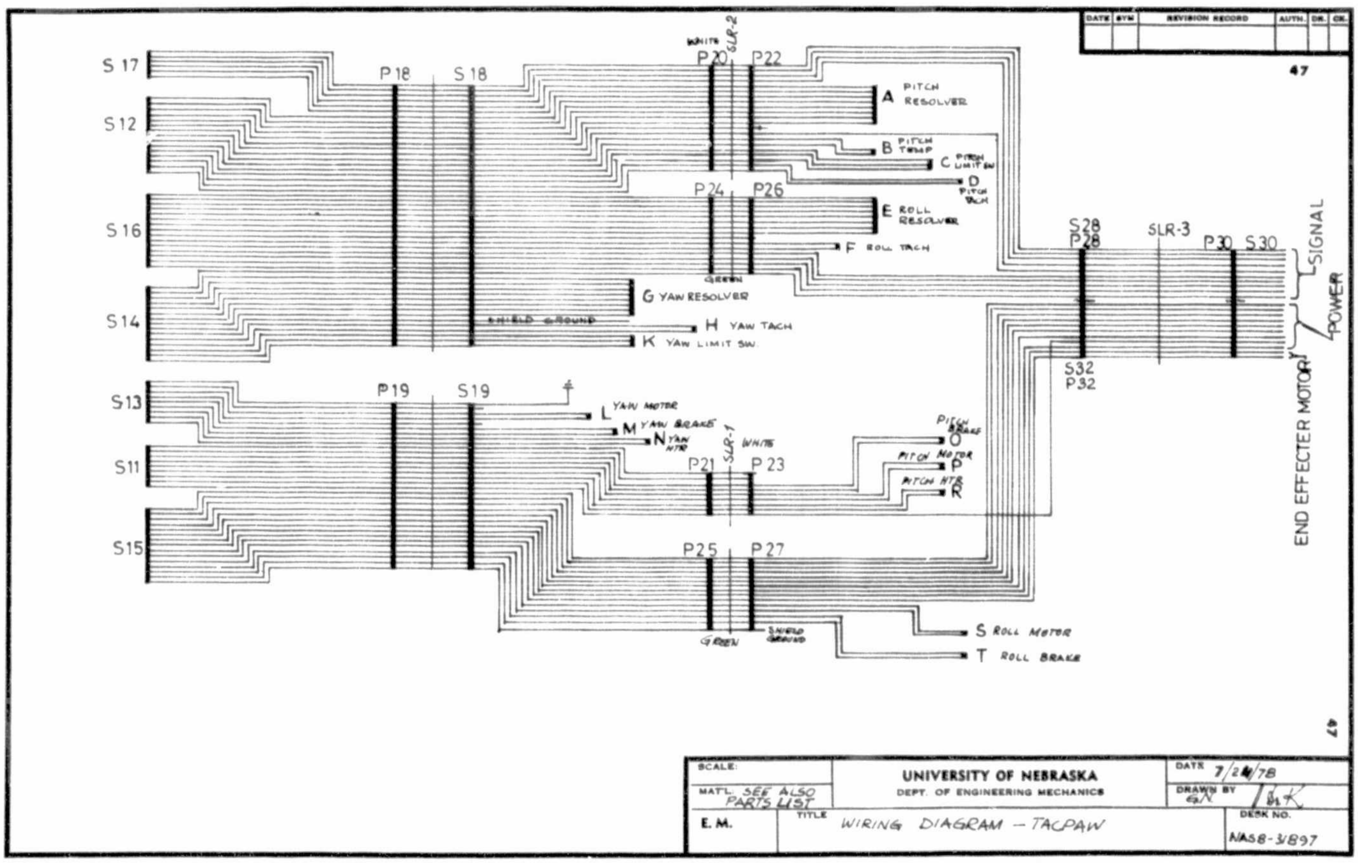


III. Assembly

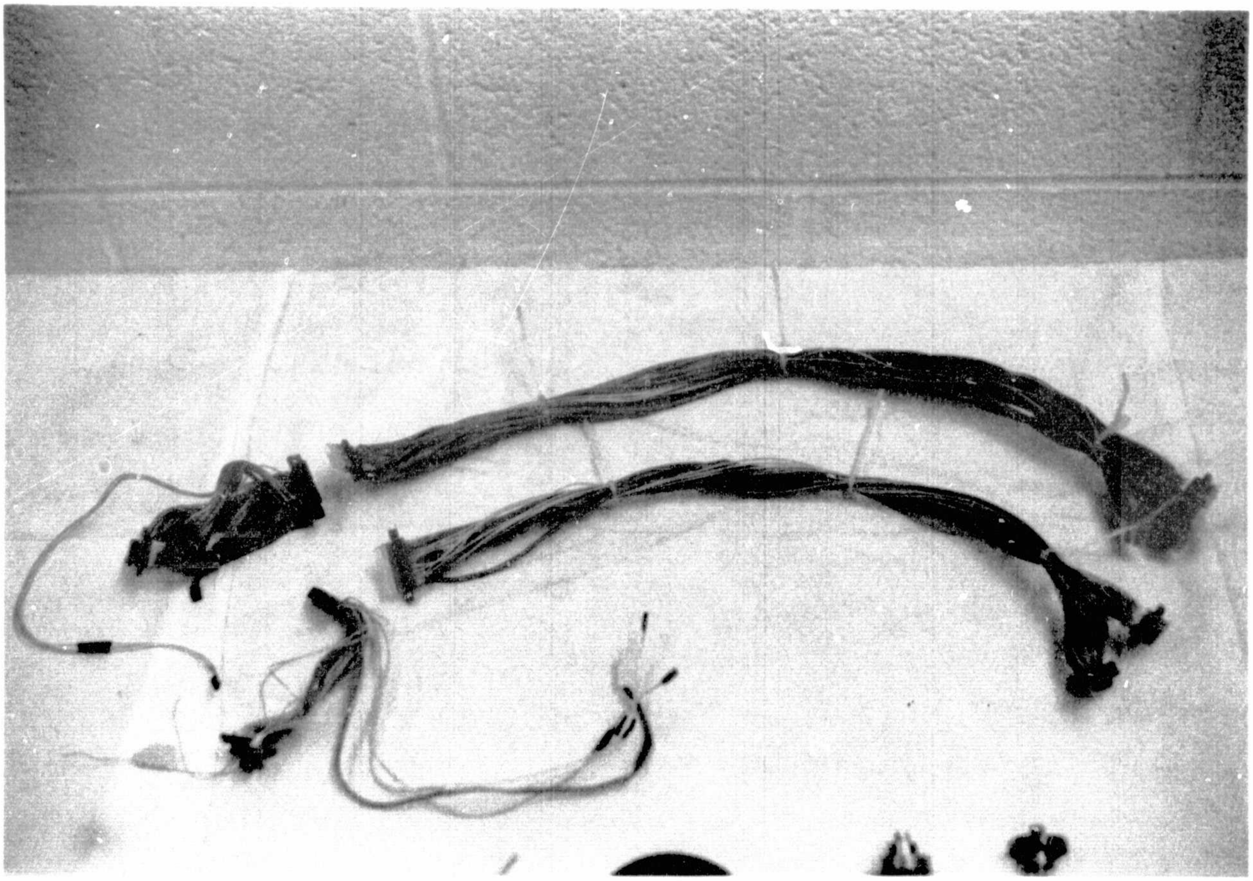
The assembly of the wrist configuration consists of two major components; the yaw enclosure and the pitch-roll enclosure.

A. The yaw enclosure.

Photograph 1 shows the various parts in their pre-assembly state. In the room where the parts were stored and assembled, a special anti-corrosion device was mounted on the wall which can also be seen in this photograph.

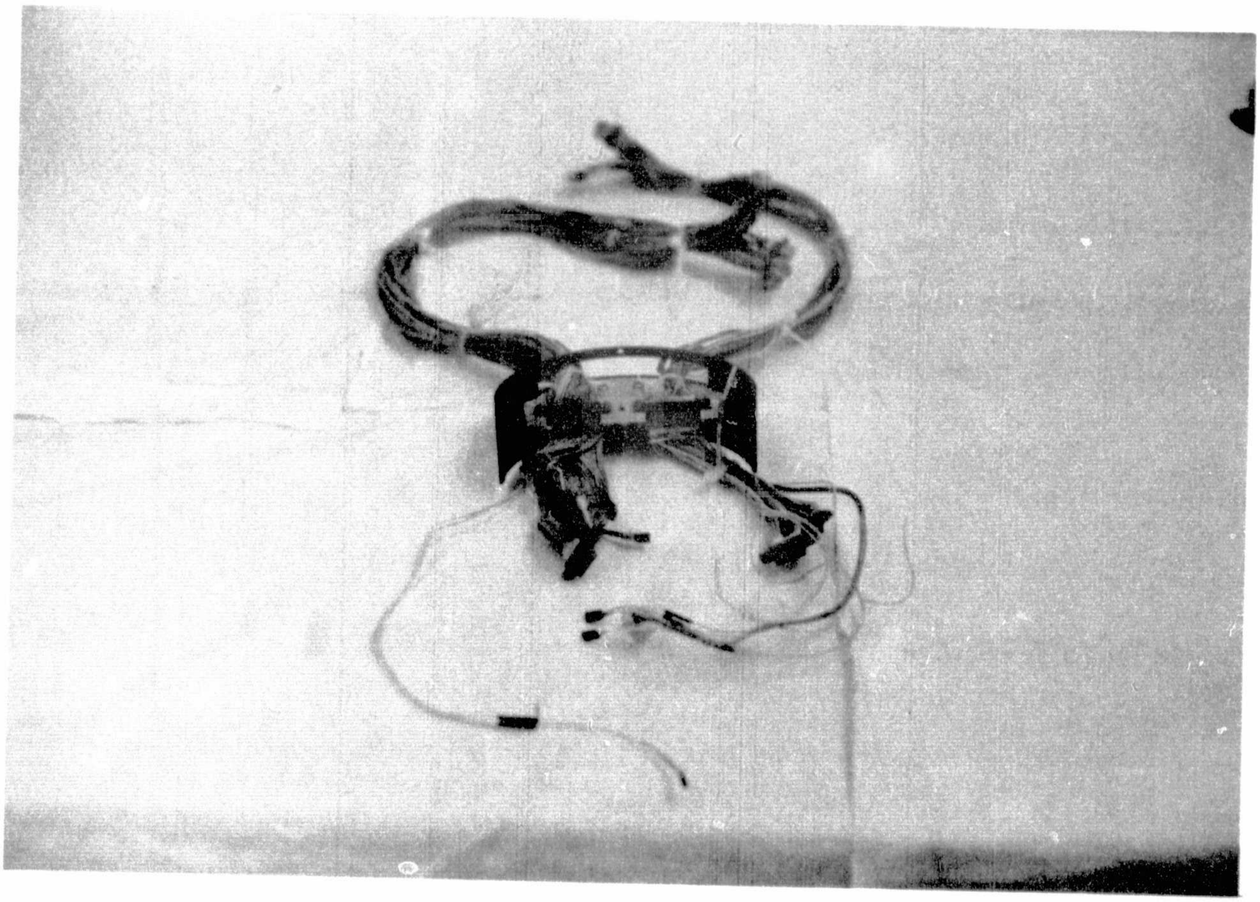
PHOTOGRAPH 1

Prior to the actual assembly of the mechanical components it is of course necessary to establish the wiring harnesses. In Photograph 2 below these harnesses are shown: the two longer harnesses are the connecting leads between the arm and the wrist. Since the actual length required for these connections was not known, a maximum of 18 inches was supplied. The two shorter harnesses are the internal connections leading to some of the electrical components inside the yaw enclosure and the majority leading to the connectors attached to the polytwist capsule. These can best be seen in Photographs 3 and 4.



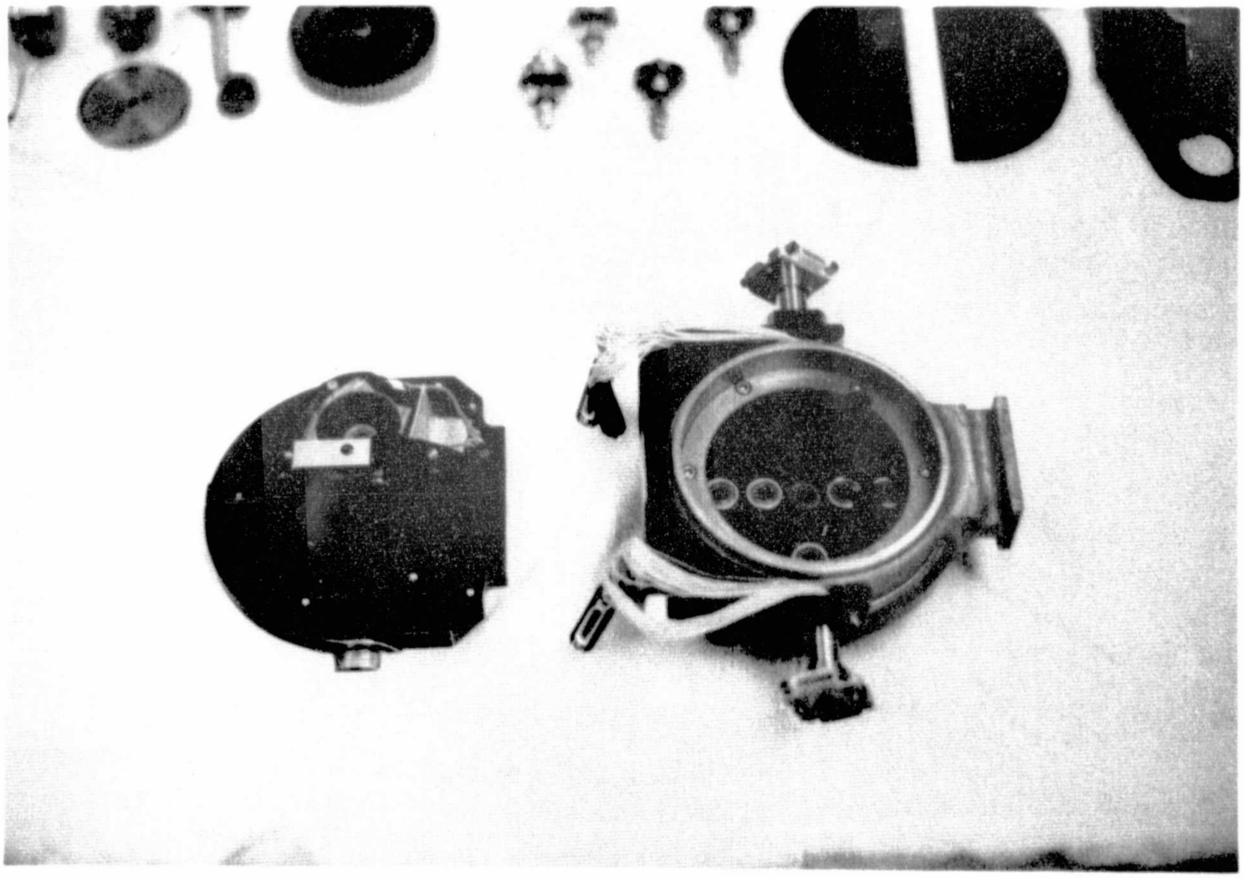
PHOTOGRAPH 2

In Photograph 3 below we see how the wiring harnesses are entering the yaw configuration and how they mate with the shorter harnesses. The wiring has been divided into a signal harness shown on the left and a power harness on the right. When facing the roll mode and viewing in the direction of the arm, keeping the harness entry slot on the top, the signal harness is left and the power harness on the right (same as in this photograph). It should also be noted that the very small connectors are the CINCH Dura Conn connectors whereas the other connectors are the ITT Cannon type.



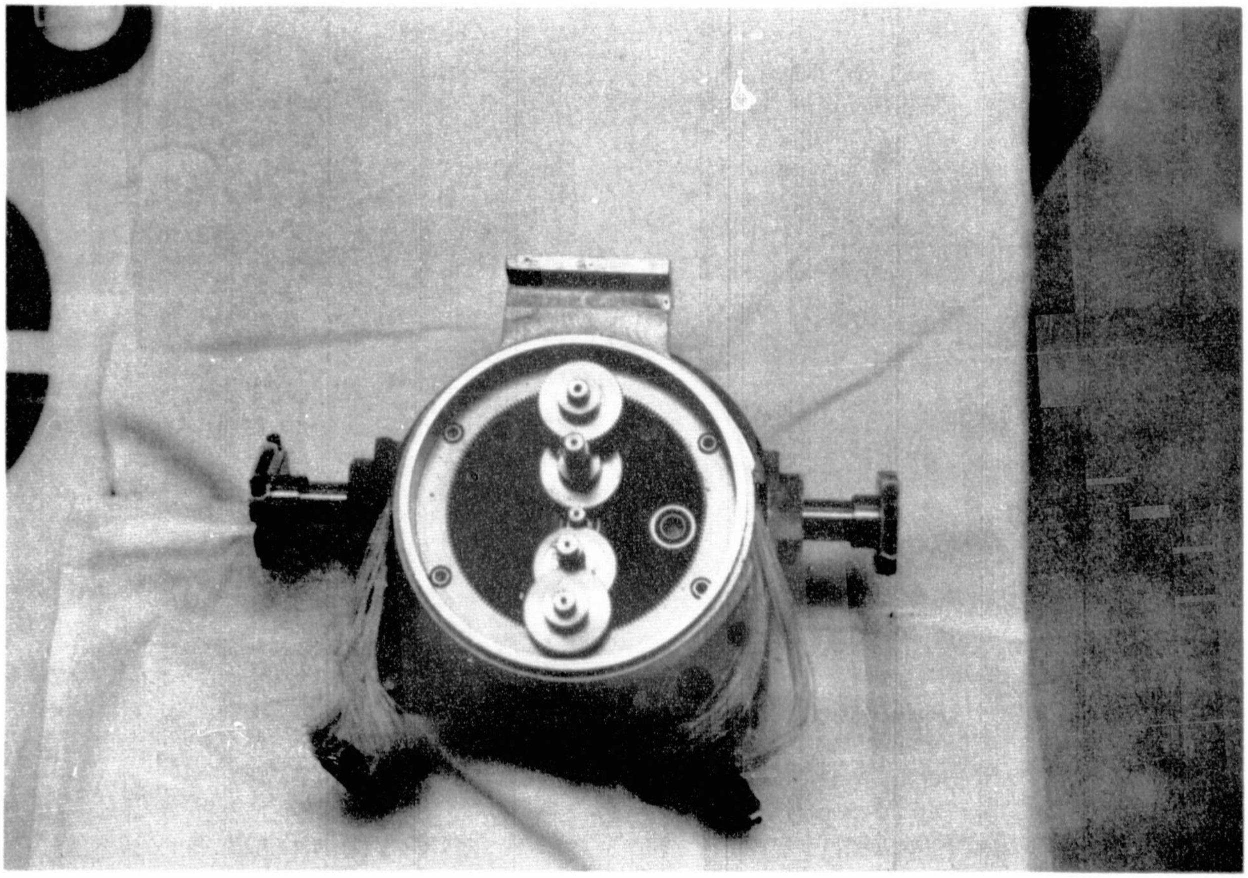
PHOTOGRAPH 3

Photograph 4 below shows a partial assembly of the yaw enclosure. Note that the pitch-axis contains the two polytwist capsules which have on the internal side the leads with connectors and on the outside the connectors are immediately attached to the twist capsule. The unit on the left is the cover plate and will be placed as soon as the gear clusters have been inserted in the unit on the right. See also photograph 5 where the gear train, which provides a 100:1 power ratio, has been placed. Photograph 6 illustrates the placement of the cover plate.



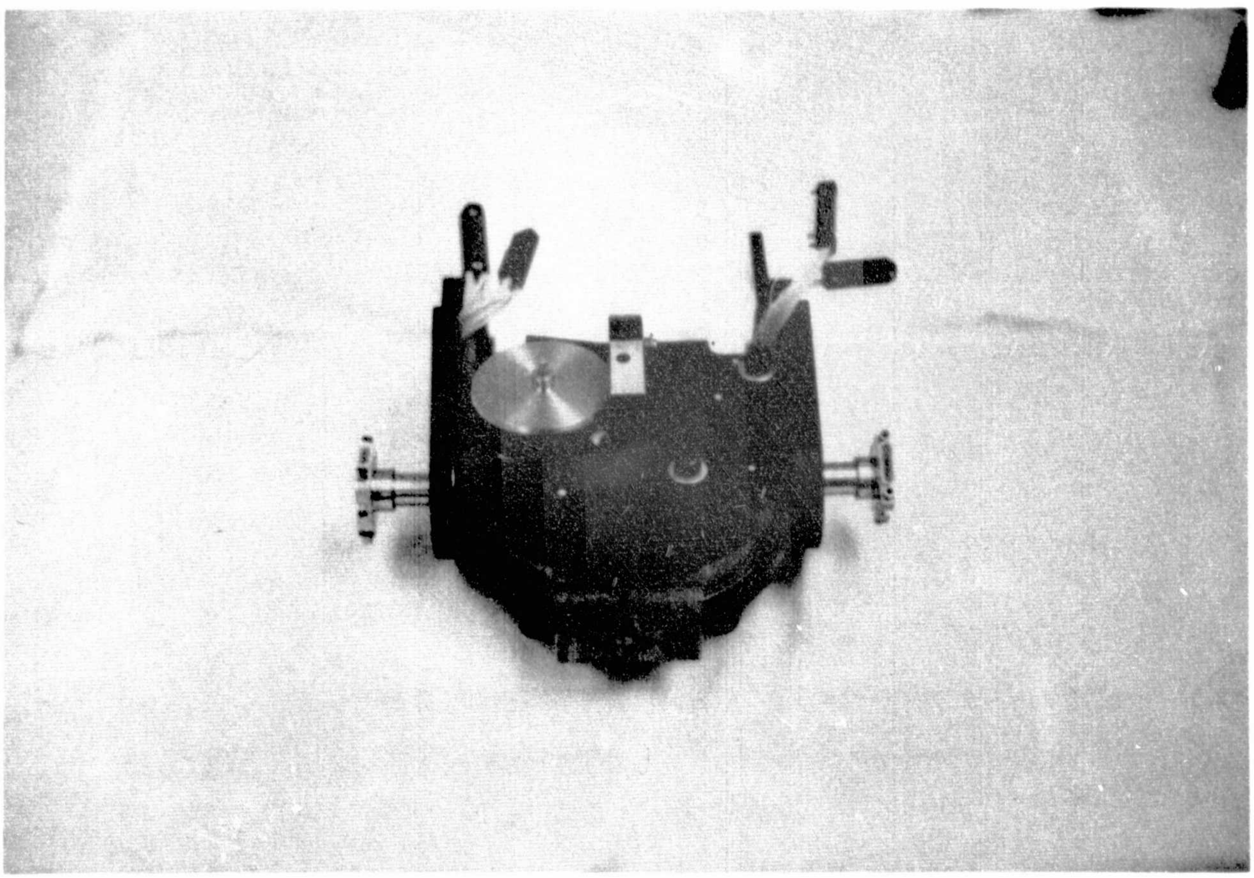
PHOTOGRAPH 4

The placement of the gear train clusters is illustrated in the Photograph 5 below. In the center of the configuration can be seen the shaft with small external gear machined unto it which is directly connected to the rotor of the DC-torquer and rotates, therefore, at the same speed as the motor. This small gear drives an identical gear train (top & bottom of photo) which, in turn, connect and mate with the internally toothed sun gear. Since the sun gear is attached to the center plate (non black) the top & bottom plate which are connected to each other as well as the motor itself can now rotate as guided by two large ball bearings.



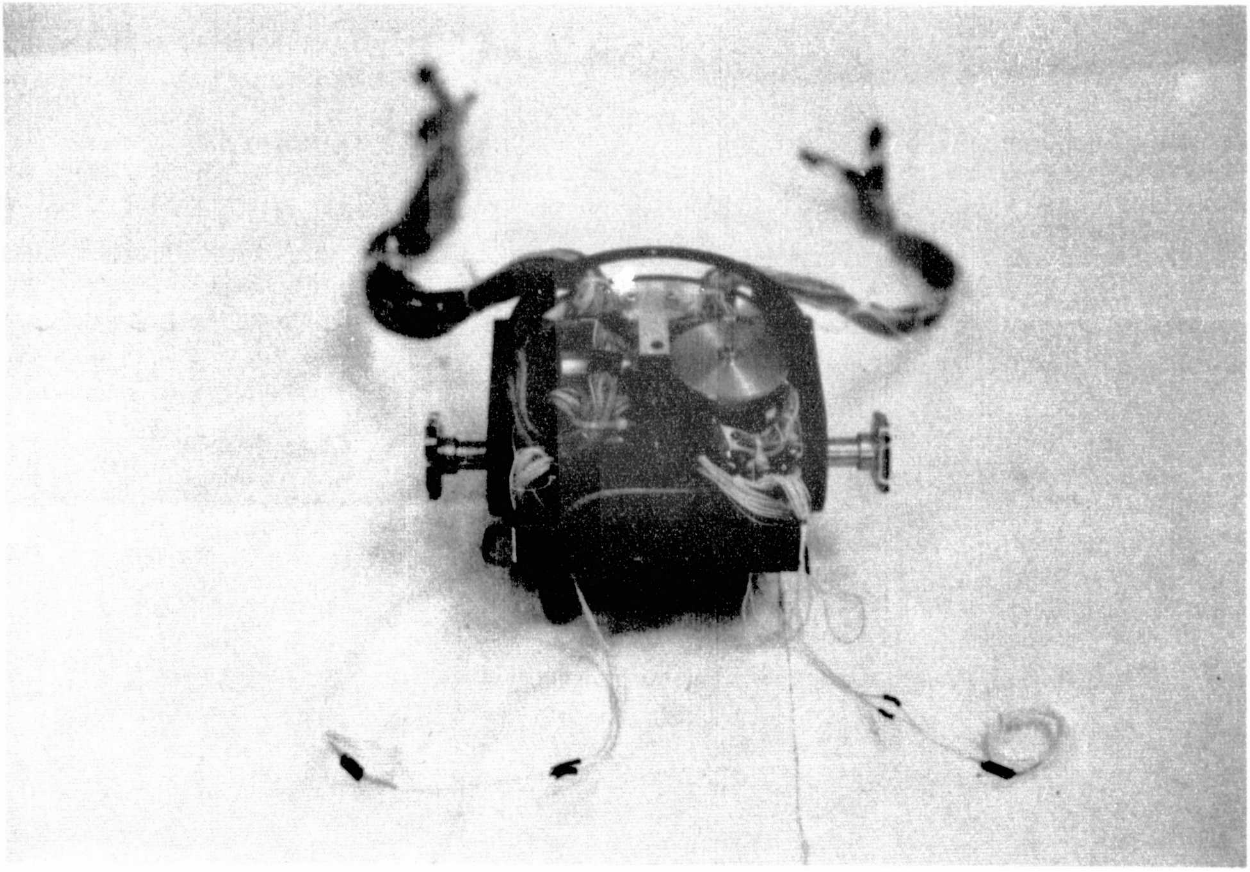
PHOTOGRAPH 5

In Photograph 6 below the top plate has been assembled which now allows for the rotation of the center ring relative to the top-bottom plate assembly. Note also on the left side the large disk, which is the bevel gear that will drive the shaft of the resolver which is to be mounted horizontally on the right side of the center upright. Below the large bevel gear, and driven by the same shaft is the tach generator already positioned and mounted. The unit is now ready to receive the back plate with the wiring harness (refer to photograph 3).



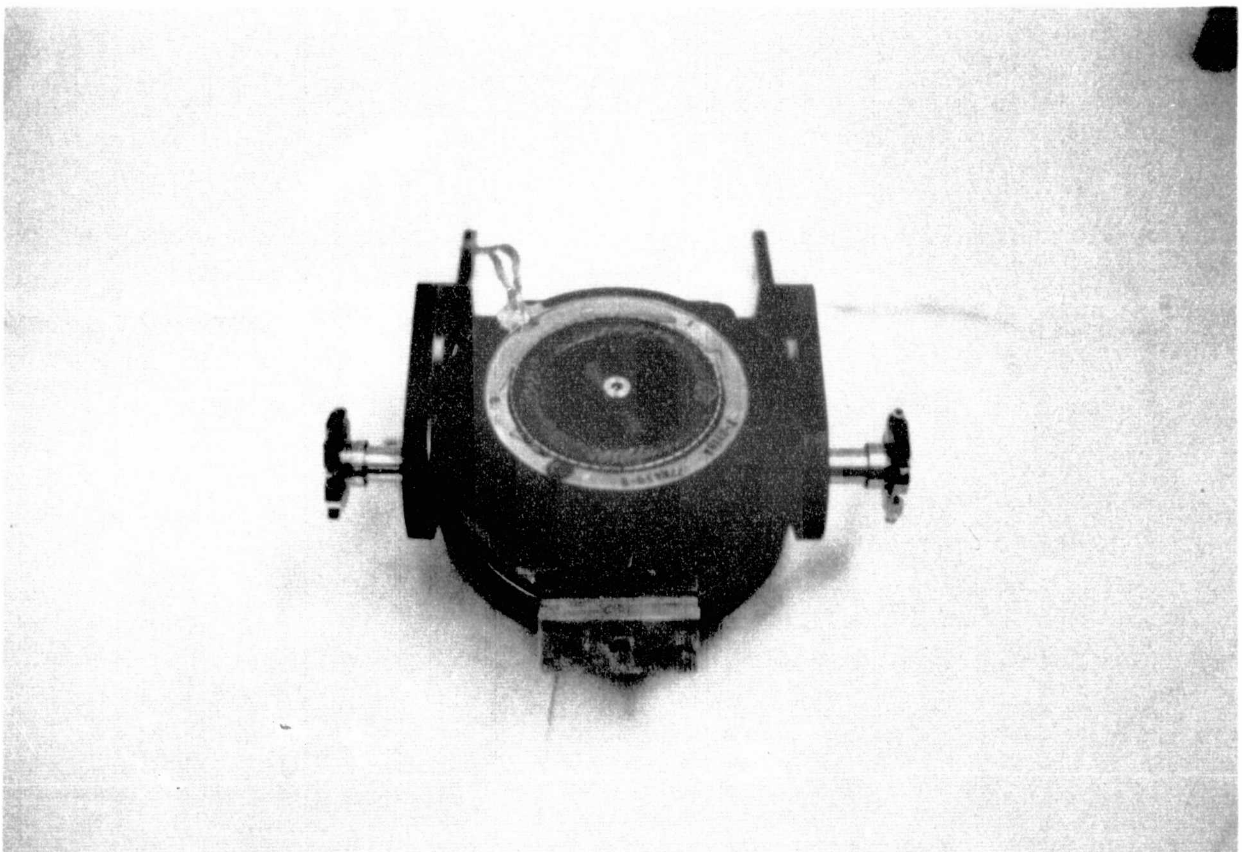
PHOTOGRAPH 6

The complexity of the unit is evident from Photograph 7 below. The resolver for the yaw motion has also been placed and is somewhat visible on the left side (horizontal mounting). The wiring harnesses have been secured at the connectors as well as by straps wherever necessary. Some of these straps show clearly in the photograph. The two wires protruding toward the reader need clarifications: the left set (3 wires) are for the connection to the yaw limit switches; the right set (2 wires) are not used but are provisions for a heater on an actual space approved wrist assembly (yaw enclosure heater only)



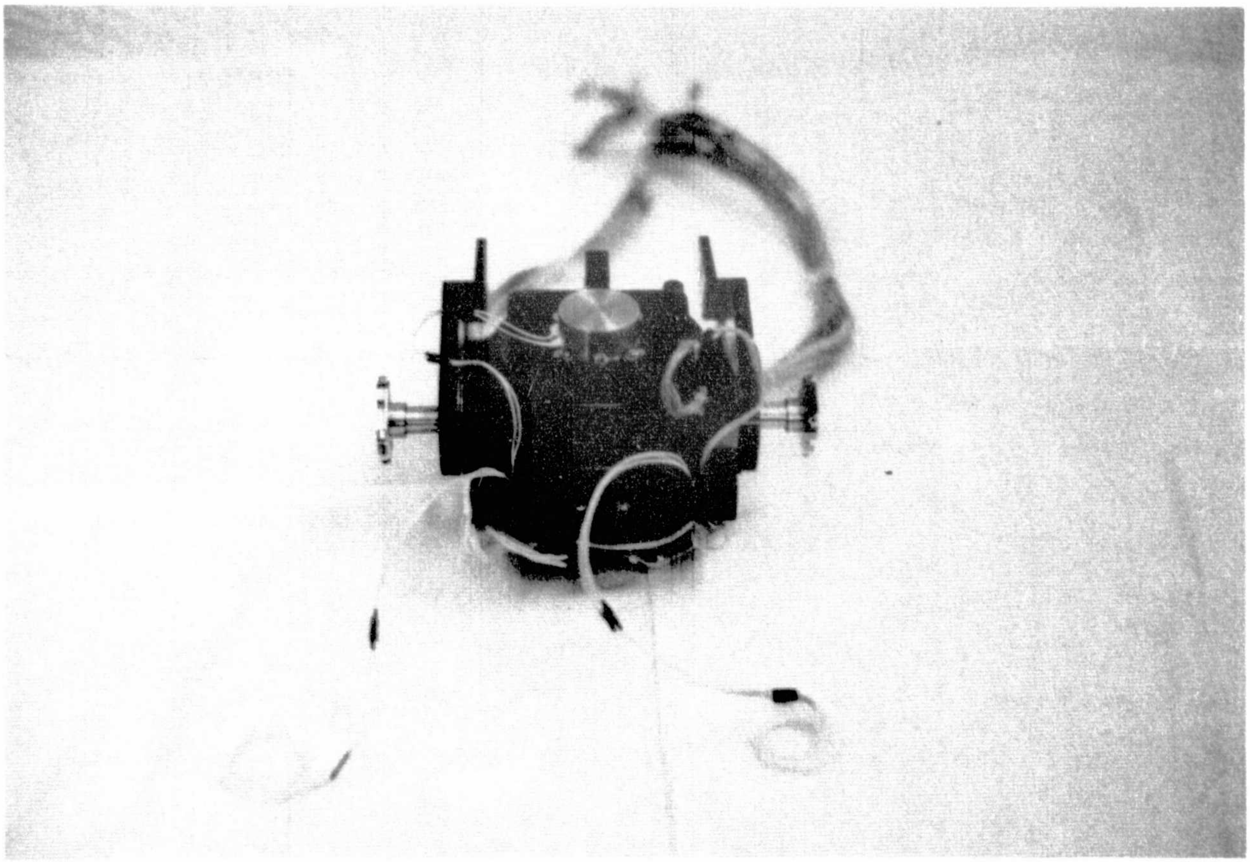
PHOTOGRAPH 7

Prior to the completion of the yaw mode, it was necessary to mount the motor for the yaw drive on the bottom plate. This is illustrated by Photograph 8 below. Note the drive shaft mounted on the rotor plate (black anodized) which in turn is connected to the rotor of the motor. The thin ring with the 4 brushes can also be seen. The wiring for the motor is attached also and enters on the left side in the photograph. The shaft has also been provided with a means to accept the brake.



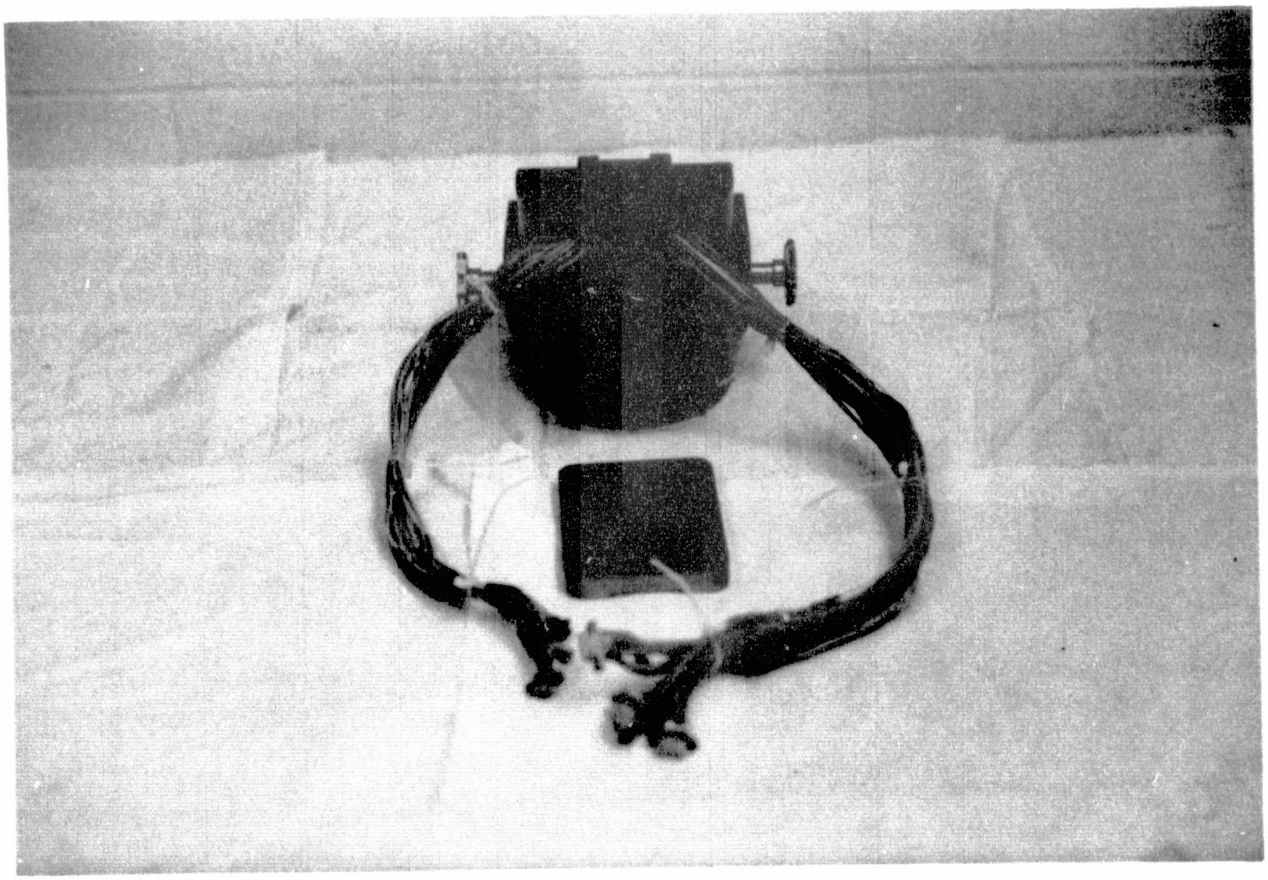
PHOTOGRAPH 8

Photograph 9 illustrates the placement of the motor cover plate and the motor-brake. To ensure that the wiring leads to the brake will not detach or break off at the housing, epoxy was used which shows clearly on the picture. Note also the CINCH Dura Conn connectors as a means to allow for interchangability of defunct parts or space approved components in case of refurbishing for a flight proto-type.



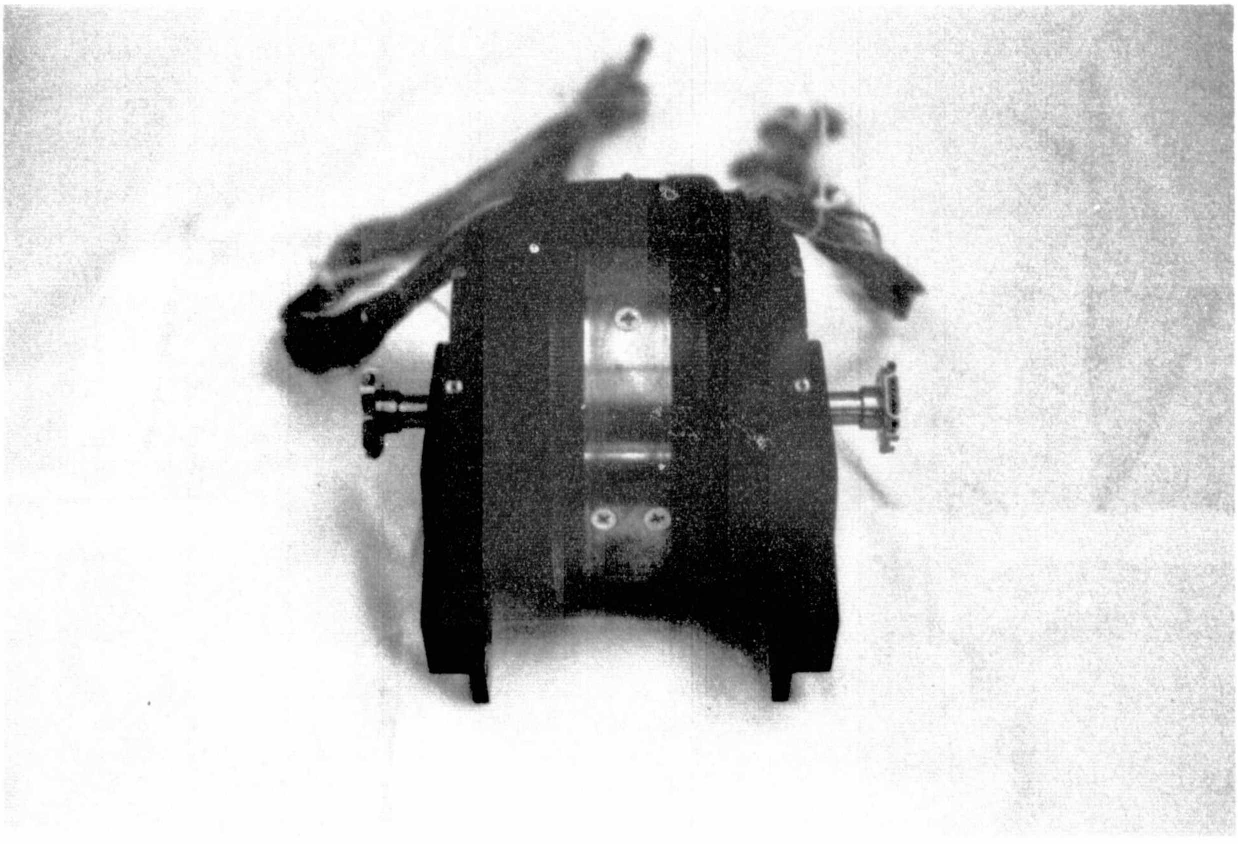
PHOTOGRAPH 9

The major effort for the assembly of the yaw mode is now complete. Photograph 10 illustrates how the 'shell' plates have been attached giving the unit a 'closed-off' appearance. The plate in the foreground is the adapter plate needed for attachment of the wrist to any one of the two arm configurations, namely the P-FMA (Martin Mariette Arm) or the ESAM (Extendable Stiff Arm Manipulator)



PHOTOGRAPH 10

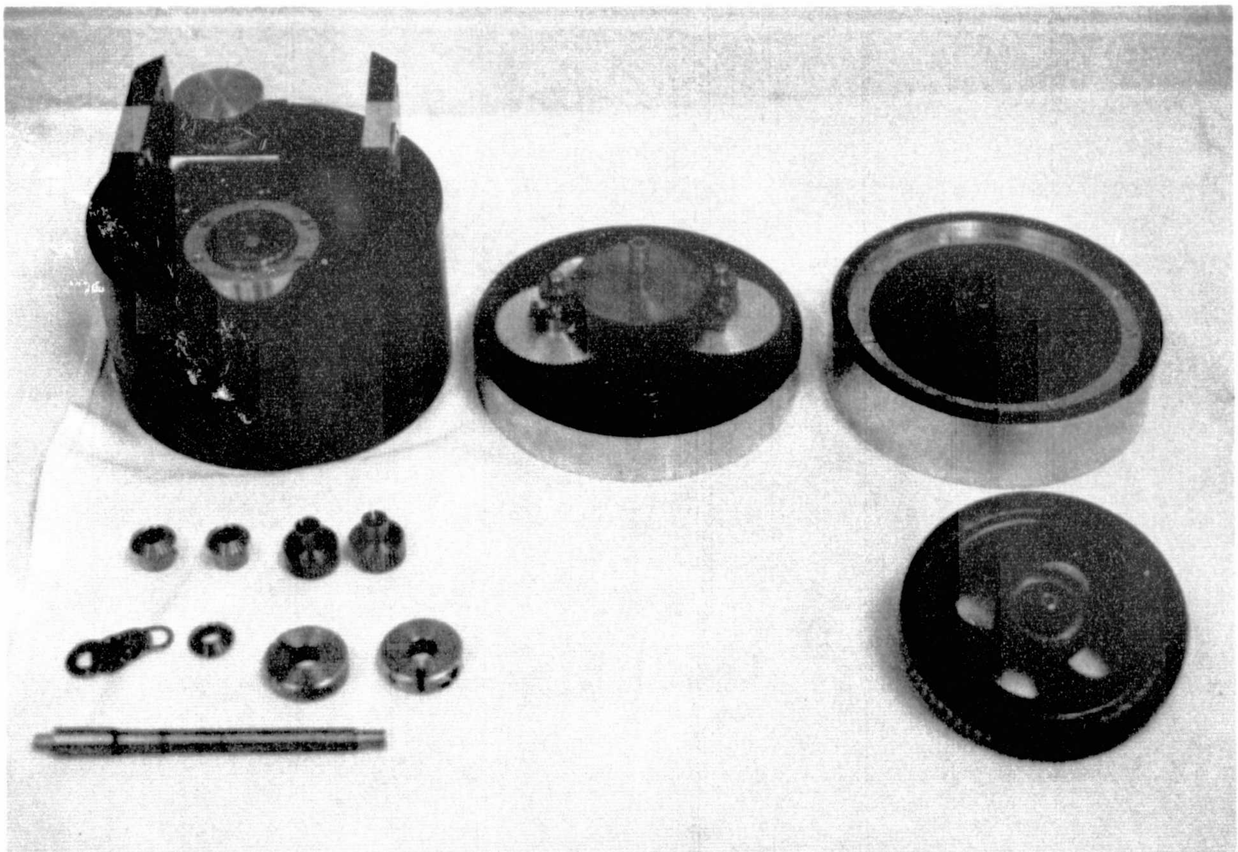
Photograph 11 is a 'front view' of the assembled yaw mode and shows the two pivot arms for attachment of the pitch-roll enclosure. The large gear segment is needed for the establishment of the pitch motion. The fabrication of this gear was made as one complete (360°) gear cut in half. The left gear teeth do not necessarily align with the right gear teeth due to two processes of manufacturing; the width of the blank did not allow for a single cutting operation. Because the tooth alignment was absolutely non-significant, a substantial savings was realized.



PHOTOGRAPH 11

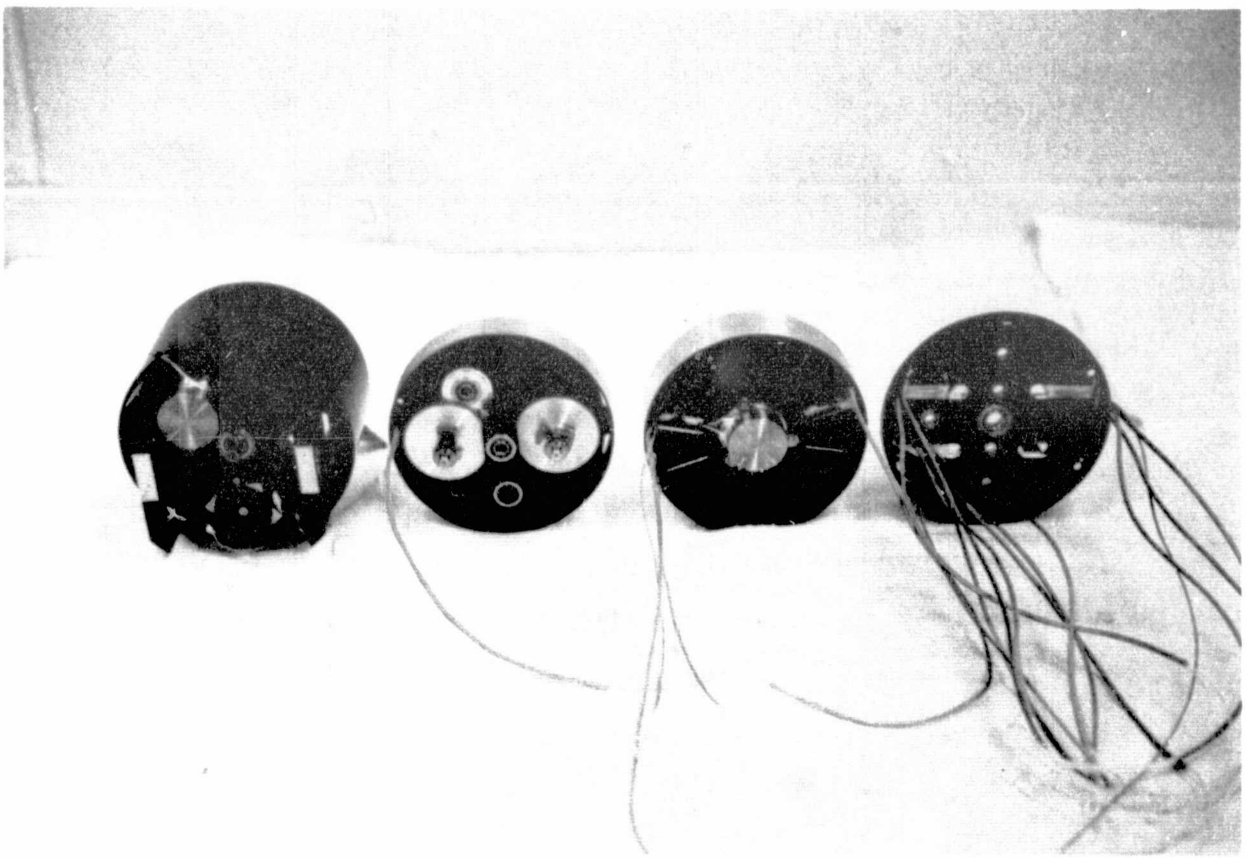
B. The pitch-roll enclosure.

Shown below in Photograph 12 are the main mechanical components necessary for the pitch motion. In the upper left corner the large pitch housing already has the tach generator and the brake attached. The gear train assembly is shown in the middle and the bevel gear main drive system is in the lower left corner. These components are external and form the mating components with the large gear on the yaw enclosure. The motor mount plate also contains the tach generator for the roll mode; see lower right corner of photograph.



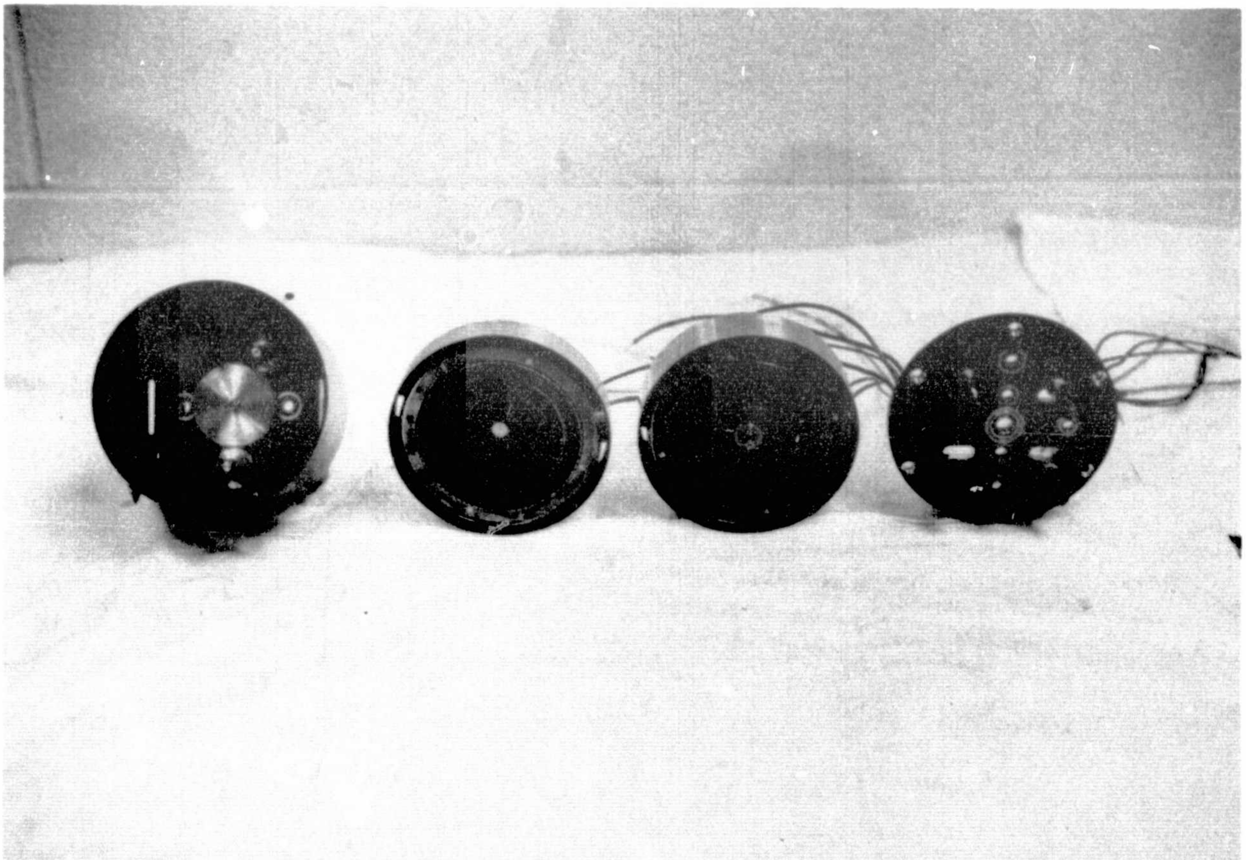
PHOTOGRAPH 12

Photograph 13 below illustrates the wiring of the various electrical components. Successive assembly from right to left is evident also from the direction of the wire leads. The two sets of slots in the wall thickness allows for the wire leads to progress toward the outside and thus mate with the connectors on the yaw enclosure. Note the brake for the roll mode in the 2nd from the right sub-assembly.



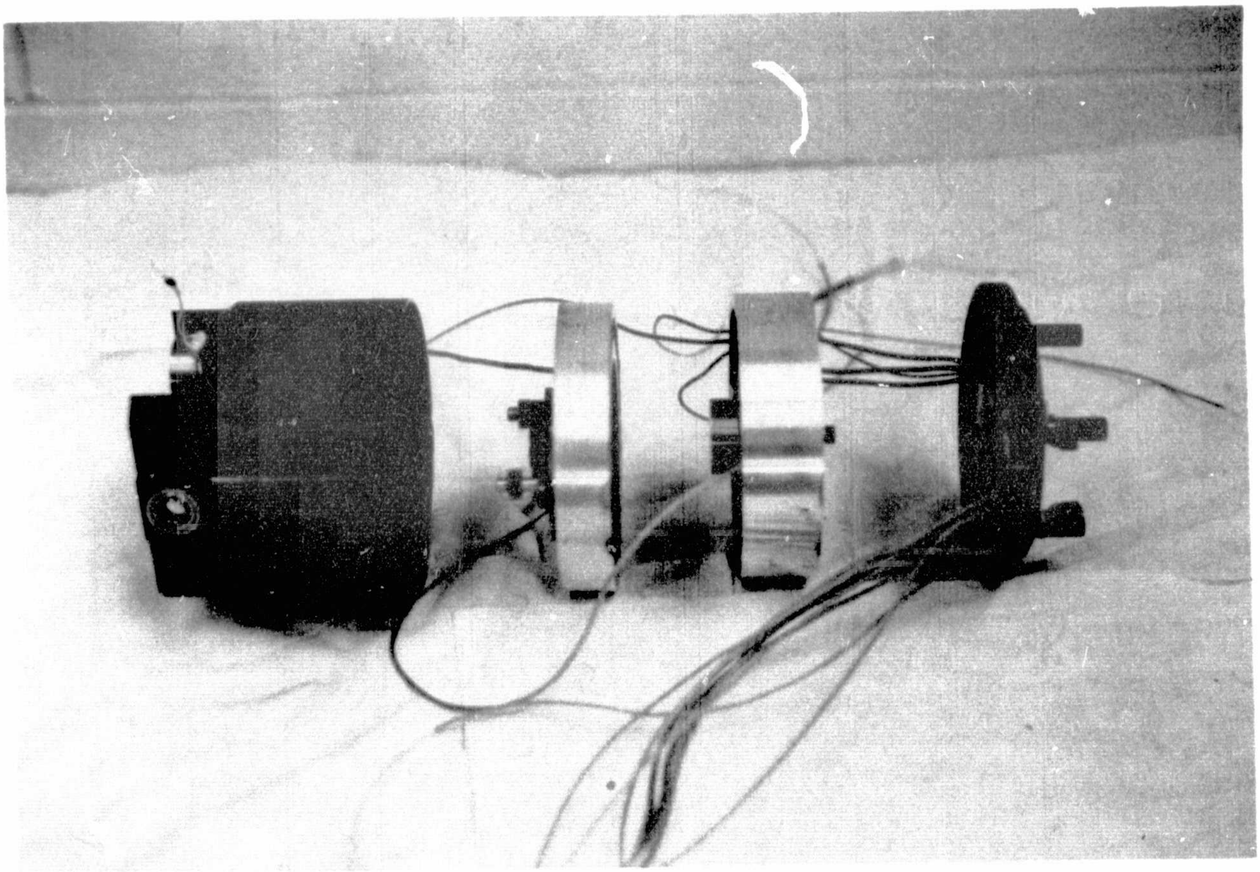
PHOTOGRAPH 13

In Photograph 14 the same components as in the previous illustration are shown but from the opposite side. The sub-assembly on the left shows the gearing necessary to drive the tach generator and brake-shaft for the pitch motion. The 2nd from the left assembly shows the motor mounted (and the brush-ring) for the pitch motion (on the back side is the gear train assembly). The 2nd from the right assembly contains the motor for the roll mode (on back side is the brake for the roll mode) whereas the extreme right assembly is the plate containing the bearings for the roll gear assembly.



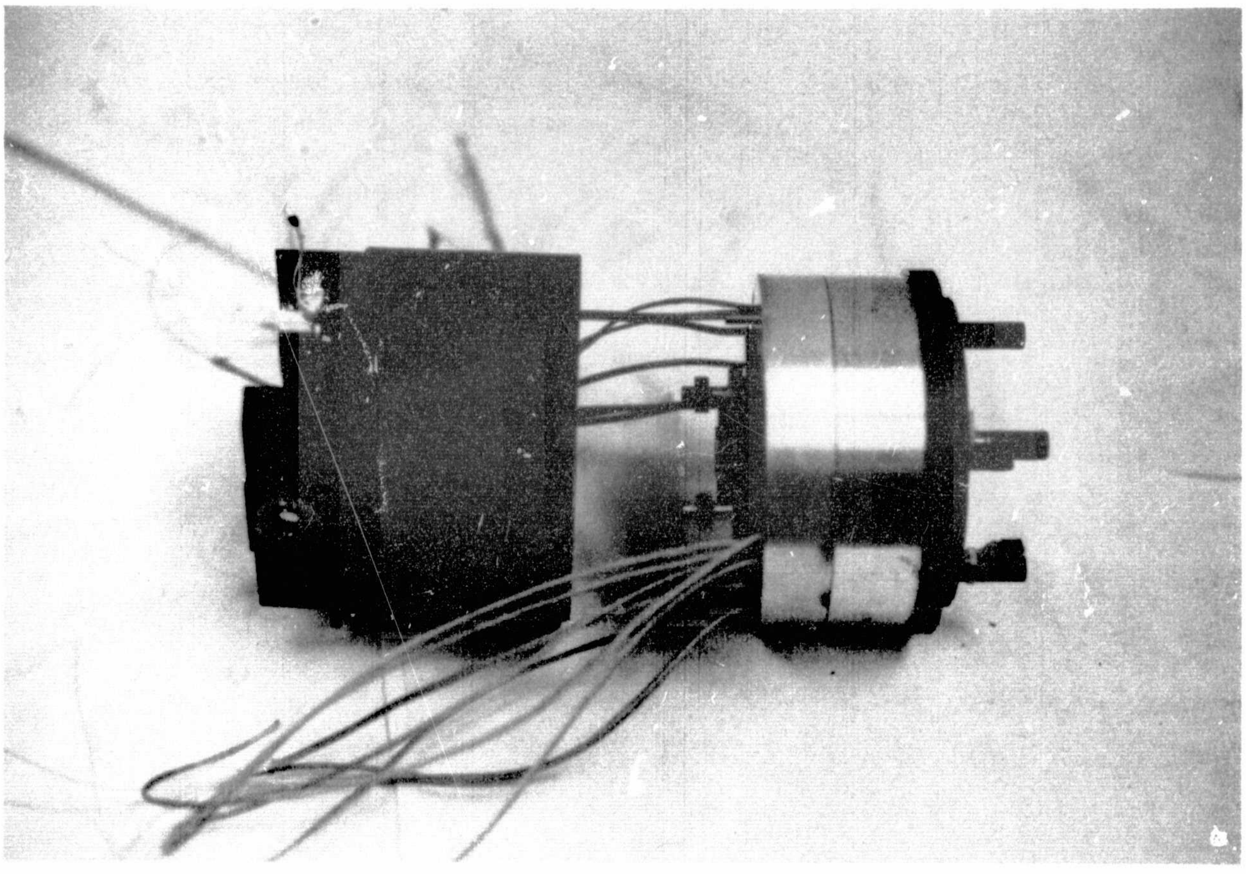
PHOTOGRAPH 14

Photograph 15 illustrates the positioning of the components from the previous two illustrations prior to their final assembly. The precision of the manufactured components now shows to be quite critical yet the tolerances provided for on the working drawings proved to be quite accurate and needed no additional machining.



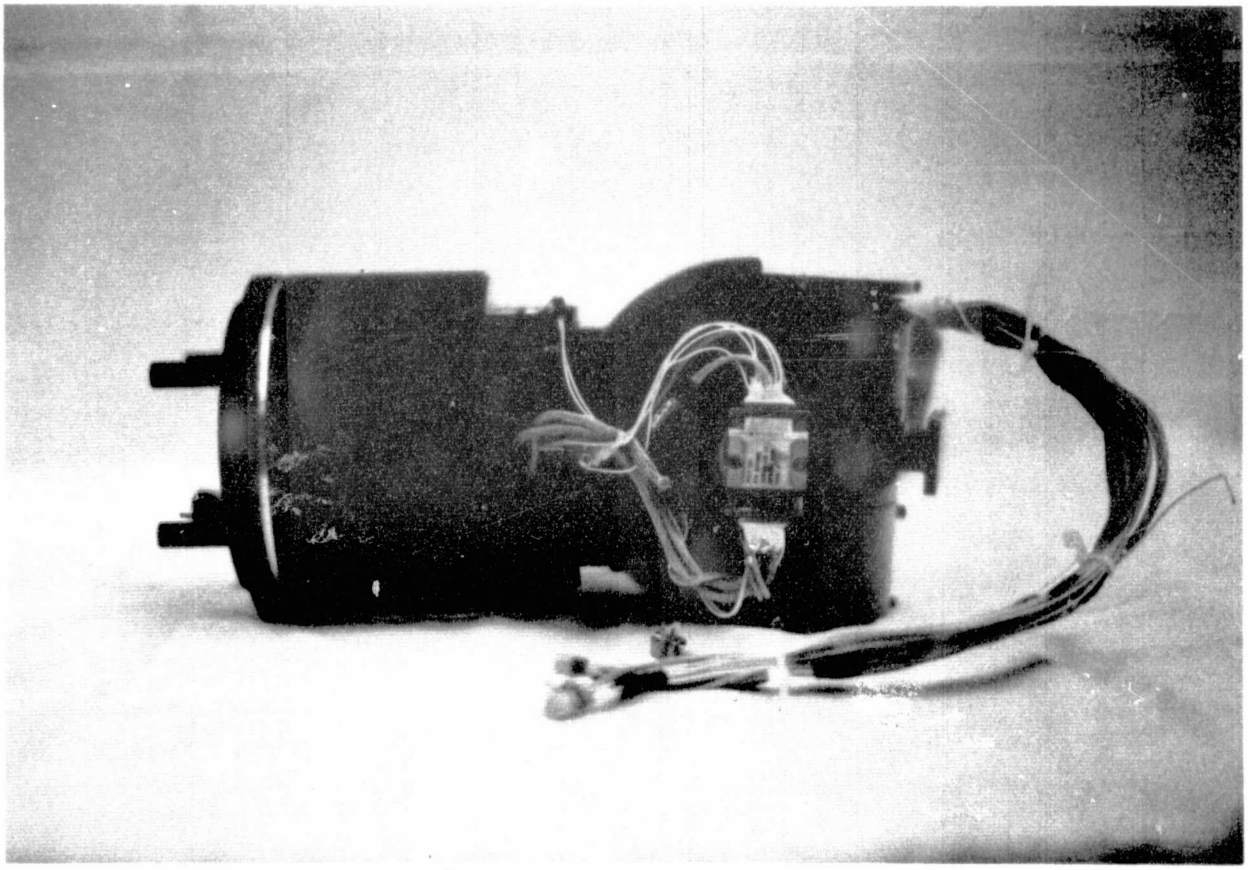
PHOTOGRAPH 15

After the wire leads have been placed in the appropriate slots (in the wall thicknesses), the subassembly shown in photograph 16 is ready for insertion into the main pitch housing. The only concern during this part of the assembly is the concern for the correct feed through of the wire leads so absolutely no pinching of the wires occurs. This was somewhat difficult to do but not an impossible task; it pays to have patience when this phase is exercised.



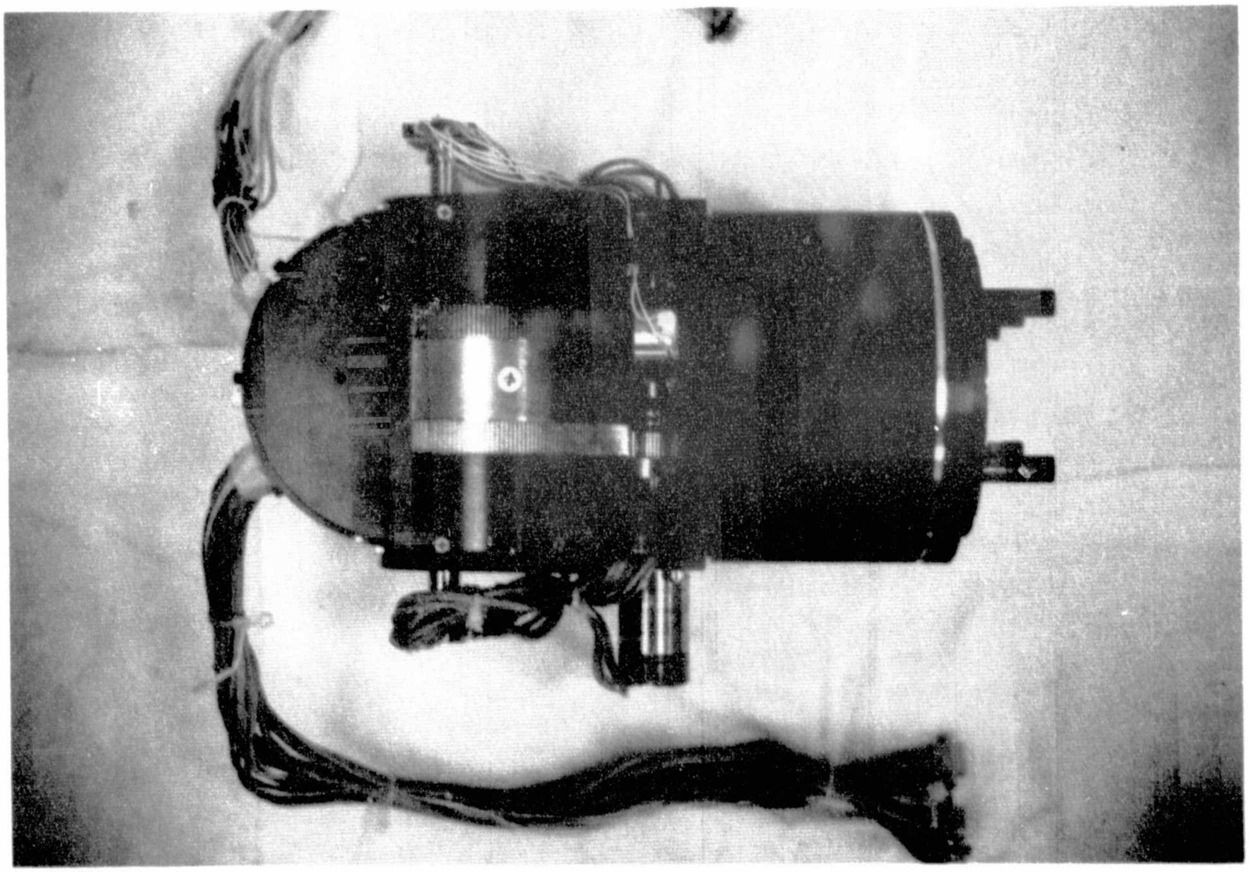
PHOTOGRAPH 16

The successful mating of the pitch-roll components from the previous photograph now allows the mating to the yaw enclosure. Thus Photograph 17 below illustrates the attaching of the yaw enclosure with the pitch section of the remaining enclosure. The wiring has been attached to ITT connectors which in turn are mated with the connectors on the polytwist cqpsule. This is the only external exposure of the wiring harnesses in the entire wrist. Since 'shelf' items were purchased for the polytwist capsules, it must be noted here that a flight prototype should encorporate twist capsules of special design to even minimize this wire exposure.



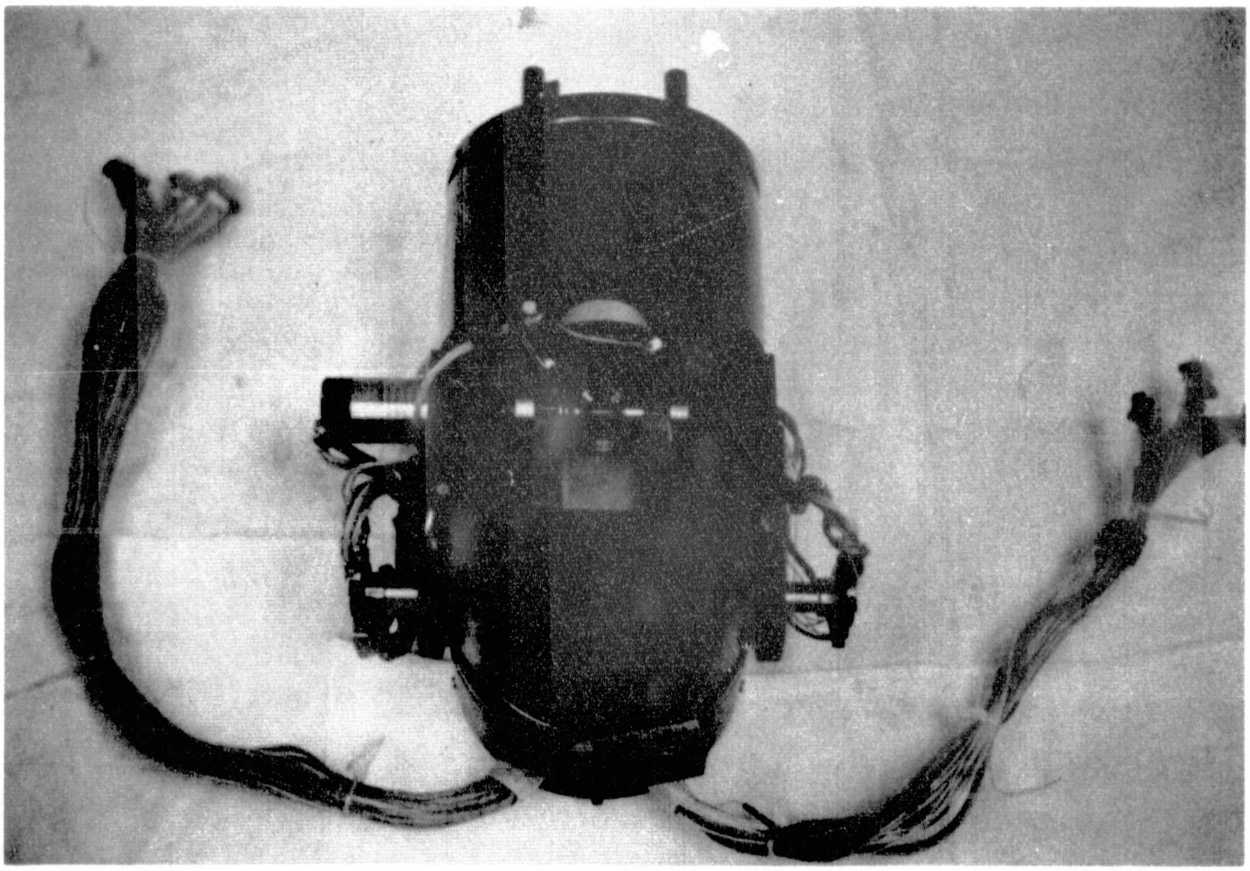
PHOTOGRAPH 17

Photograph 18 below is a top-view of the nearly completed wrist unit. Note the extended resolver used for monitoring the pitch motion. Again, shelf items were used but it is recommended that smaller pan-cake type resolvers can be substituted for an actual flight proto-type. This resolver is mounted directly on the shaft which drives the pitch motion gears; the pitch brake is also clearly visible.



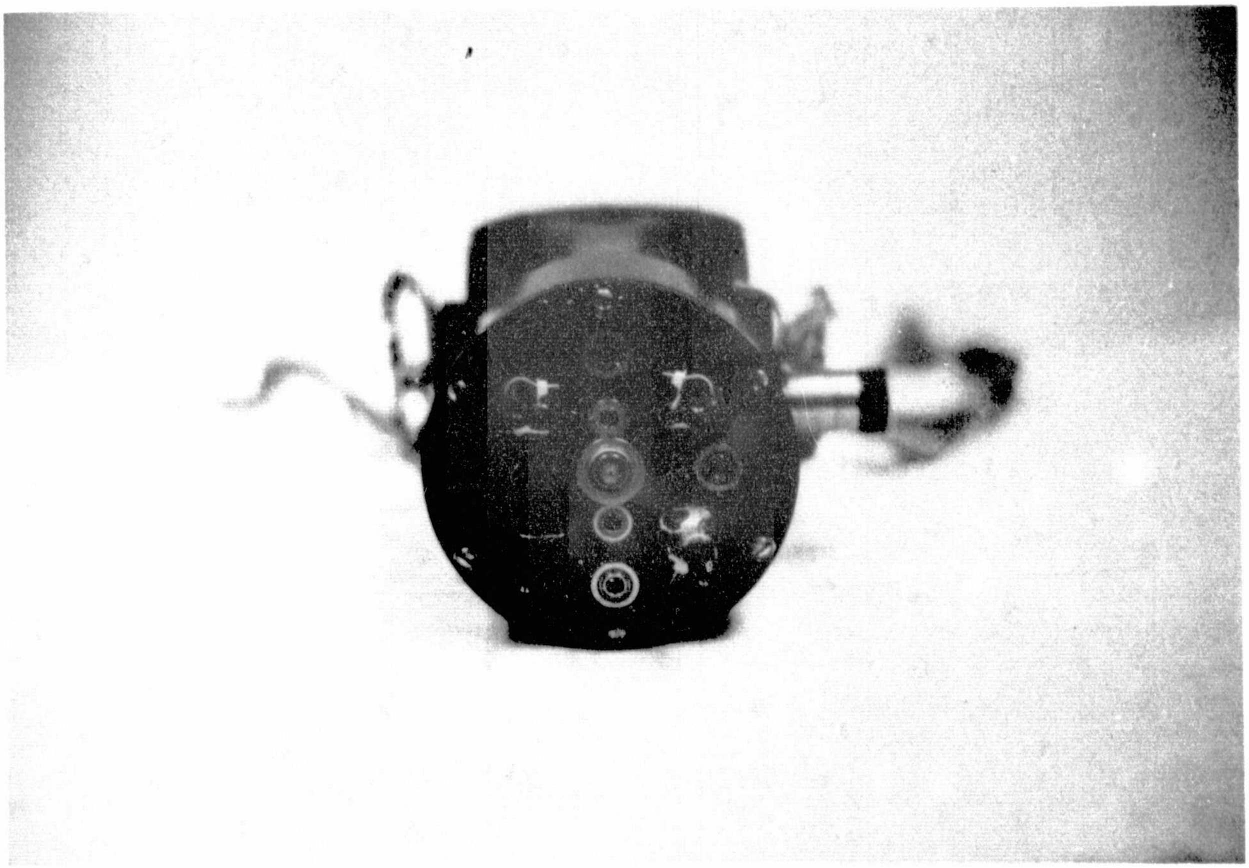
PHOTOGRAPH 18

The bevel gear drive to enable the pitch motion to take place are clearly visible in Photograph 19, as well as the two spur gears which mate with the large gear on the yaw enclosure. At this stage of the assembly the final steps can be exercised, namely the additional roll-mode components.



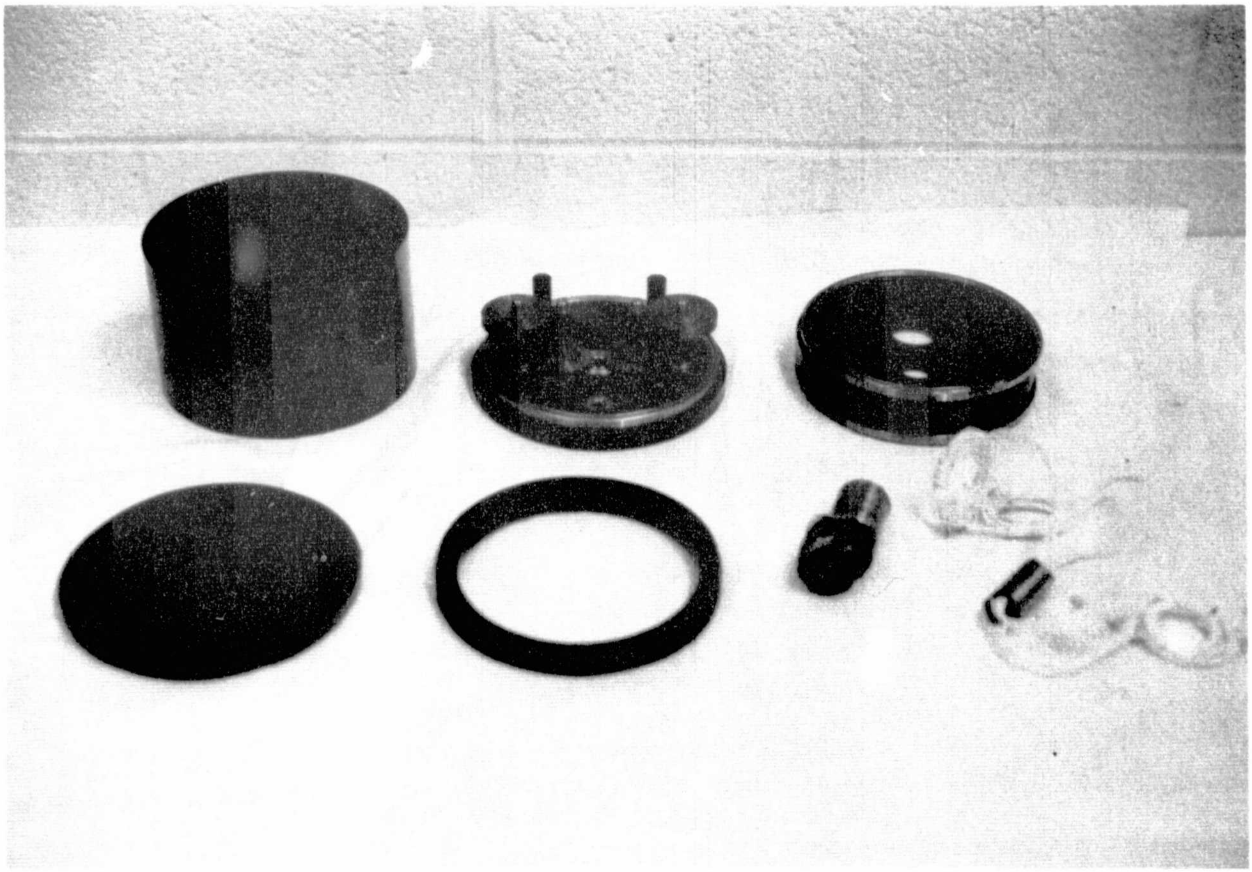
PHOTOGRAPH 19

This head-on Photograph 20 depicts the various bearing locations which are necessary for the gear train assembly of the roll mode. The center gear is the small drive gear which will mate with the gear train. It should be remembered that up to now the components are considered to be fixed or stationary; the remaining components will thus rotate and cause the continuous roll of the entire wrist assembly.



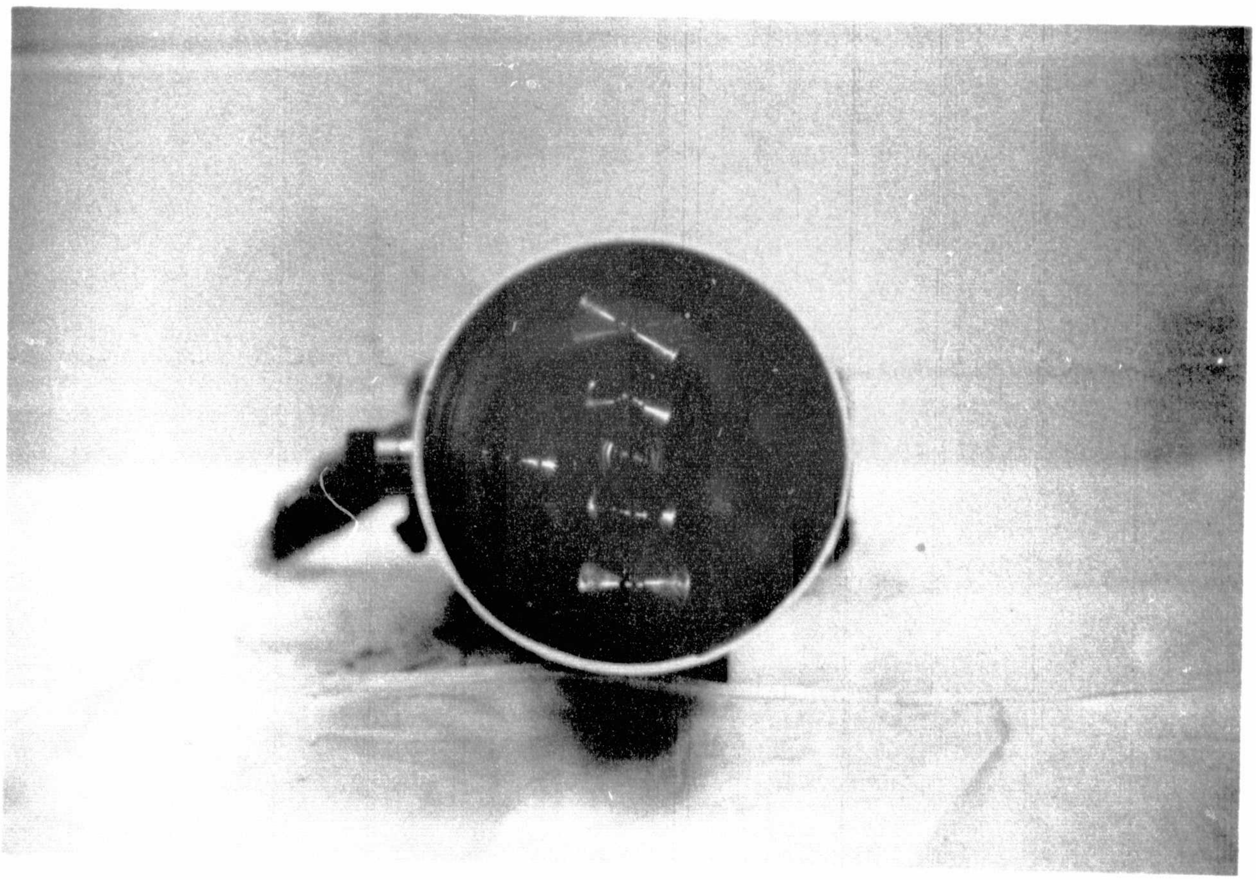
PHOTOGRAPH 20

Photograph 21 below illustrates the major mechanical and electrical components of the roll mode portion of the wrist. The upper left corner shows the roll housing to which the end flange (lower left) is attached by means of the screw ring (lower middle). In the upper middle the positioning of the gear train assembly is shown (the plate is the end plate seen in photograph 22). The upper right corner shows the two ring bearings mounted on a plate which attaches to the posts shown on the plate containing the gears. The lower right corner depicts the roll mode resolver and the poly scientific slip ring for providing 21 leads in continuous roll capability.



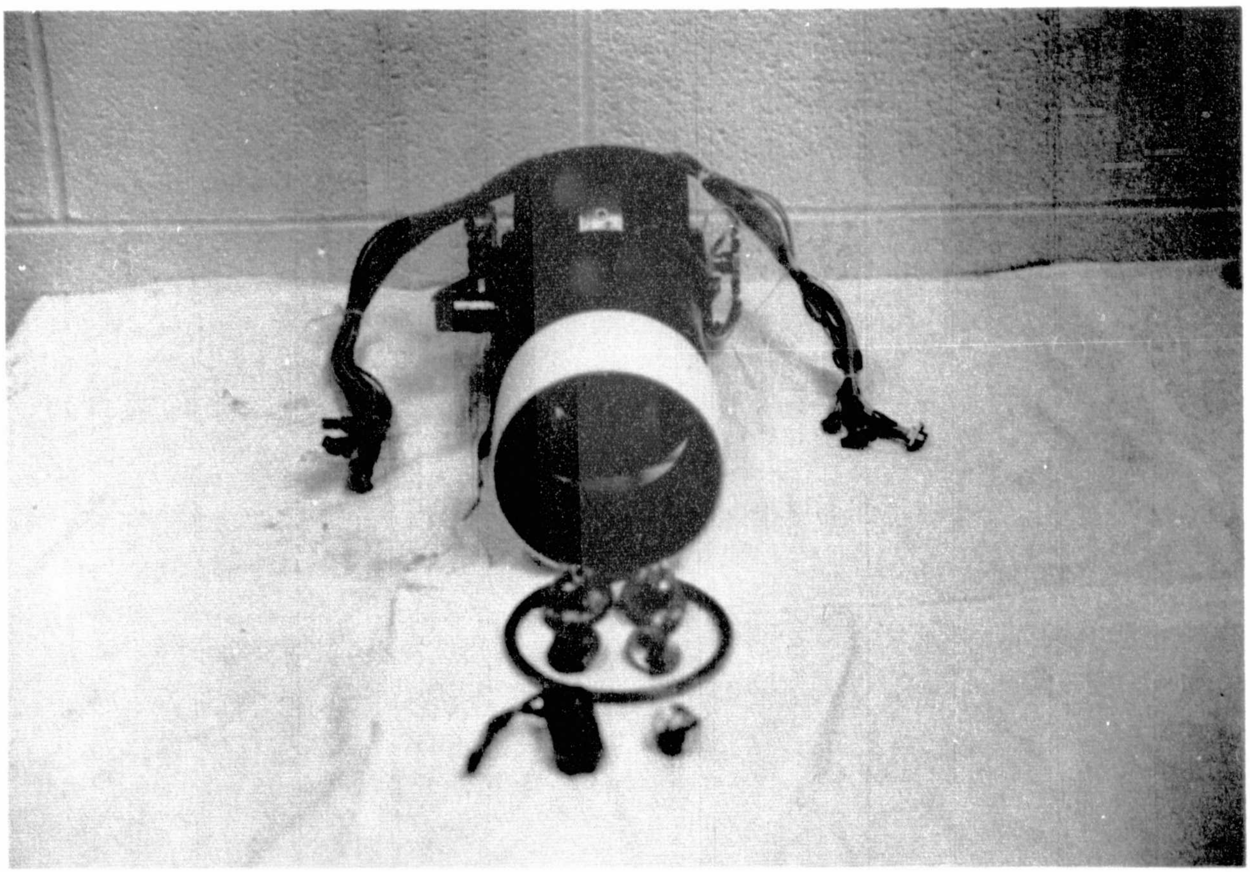
PHOTOGRAPH 21

The gear train assembly seen in Photograph 22 not only illustrates the double drive on the large internally toothed sun gear but also the drive means for the resolver shaft. This is accomplished by allowing the sun gear to drive the small gear on the left (and middle). Remembering that the drive pinion is stationary, this makes the sun gear rotating, and thus allowing the resolver shaft to be stationary also.



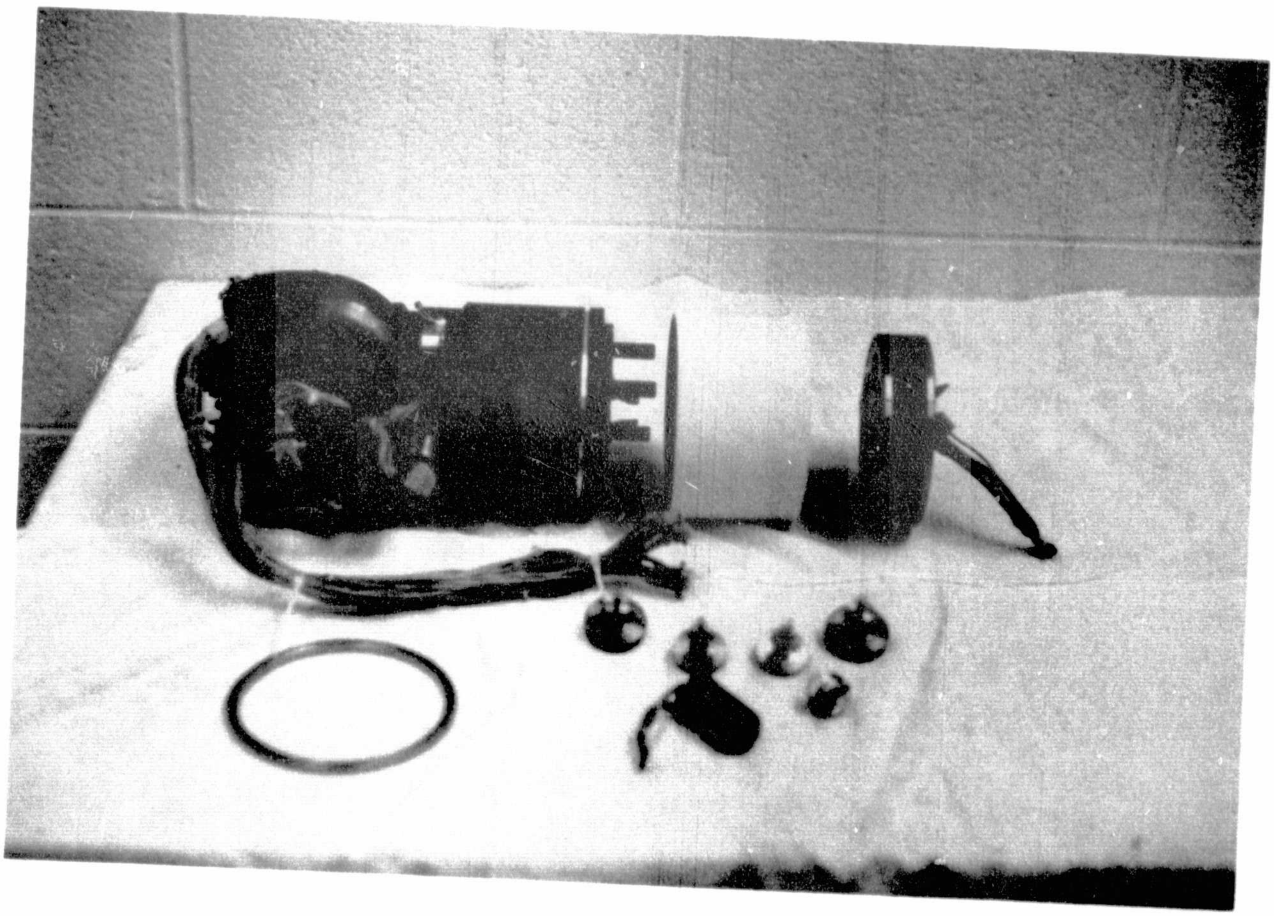
PHOTOGRAPH 22

Whereas the previous photograph depicted the gear train already assembled, Photograph 23 below is intended to show the relative positioning of the parts with respect to the entire structure prior to assembly. The pitch resolver is also shown in the foreground.



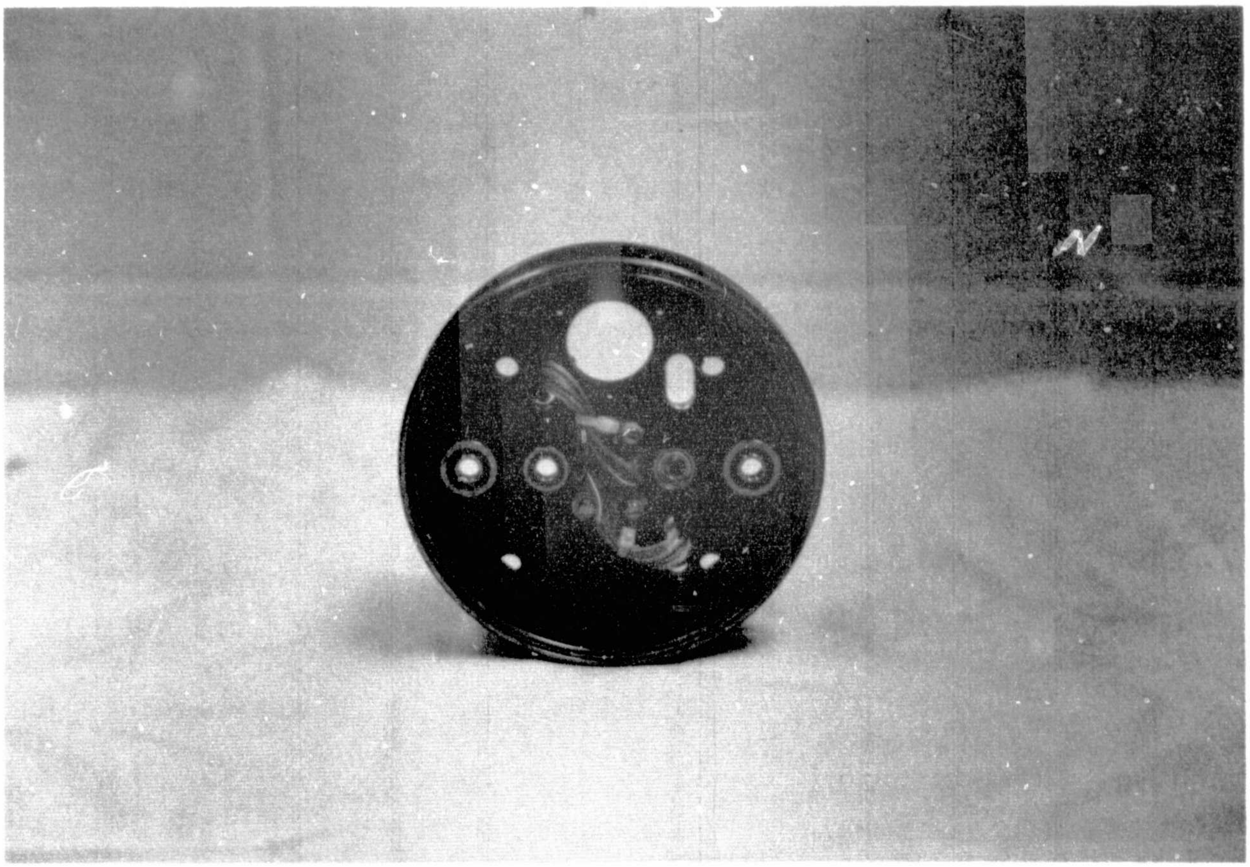
PHOTOGRAPH 23

Photograph 24 below is a side view of the previous illustration showing also the mounting plate for resolver and slipring.



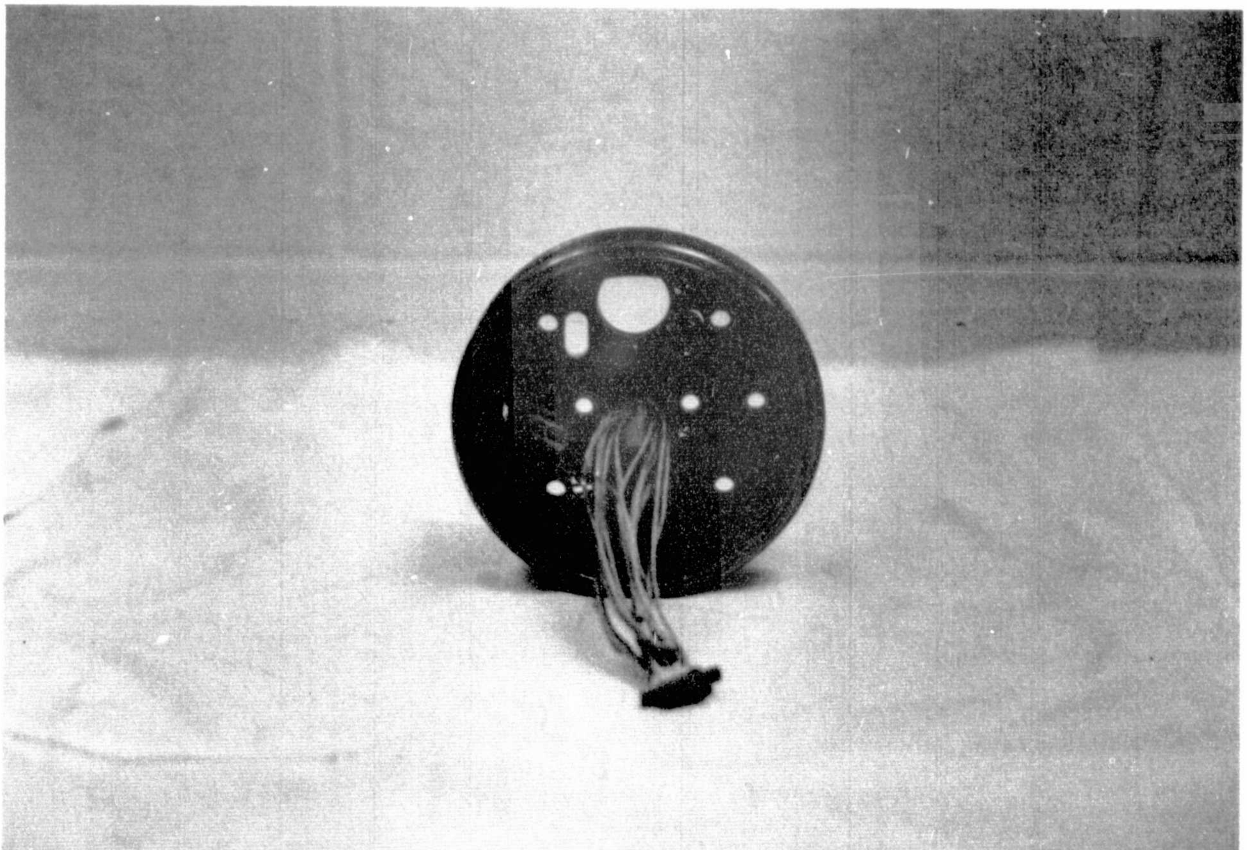
PHOTOGRAPH 24

The slipring, providing the 21 wire leads to the end plate, is shown mounted and wire connected in the middle of Photograph 25. To facilitate connection of CINCH Dura Conn connectors, the 'entry' leads have been passed through slots as shown. The side shown is the internal side of the mount plate (see also previous photograph). Note the large hole for the mounting of the resolver for the roll mode.



PHOTOGRAPH 25

Photograph 26 is the reverse side of the previous photograph and shows the exit leads from the slipring. These leads, provided with an ITT Cannon plug will exit through a suitable hole in the end cap and will rotate (continuous roll capability). The photograph also shows the CINCH connectors quite clearly.

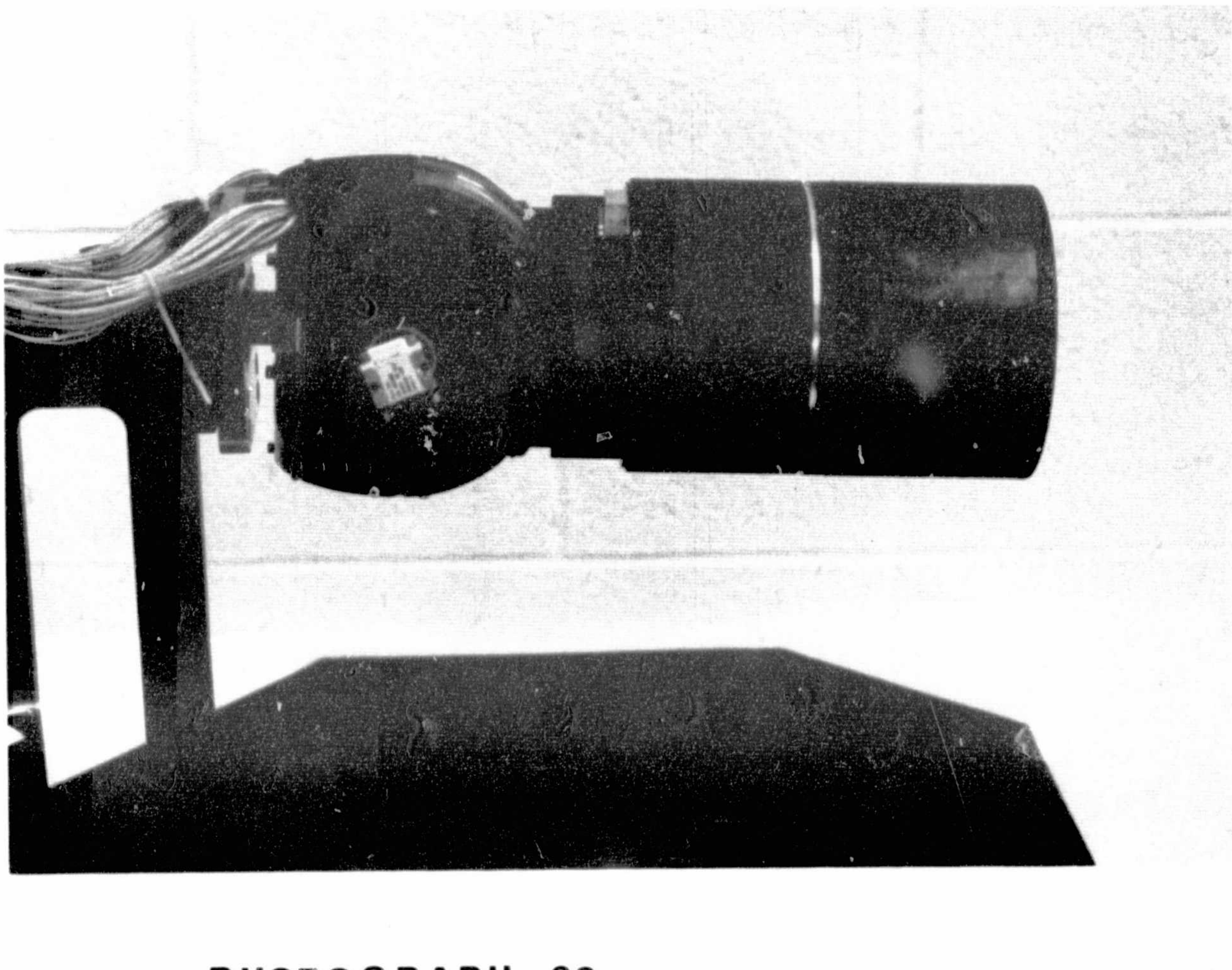


PHOTOGRAPH 26

With the exception of the end-plate, Photograph 27 shows the completed assembly; particularly it is intended to show the roll mode resolver in place. The selected length of the slipring leads is purely depended upon the end-effector and its configuration as well as mounting structure. To enable the testing of a wide variety of possible end-effectors, the lead length was selected as 12 inches but a much shorter length is certainly possible. Note that the wire leads are shielded wherever possible.

PHOTOGRAPH 27

Photograph 28 shows the entire TACPAW assembly mounted on a test plate. The leads from the pitch-roll mode have not been attached yet. In fact, this picture was made during the pre-final assembly phase when all components were assembled without wiring in order to determine the correctness of the machined parts and the correctness of the many shaft-bearing alignments. Photograph 29 shows the TACPAW as it was delivered to Mr. J. O. Johnston (on the left) at MSFC by principal investigator Dr. Leendert Kersten.



PHOTOGRAPH 28

PHOTOGRAPH 29

ORIGINAL PAGE IS
OF POOR QUALITY

IV. Conclusion

The completion of Phase II, the building of the prototype TACPAW under contract NAS8-31897 certainly turned out to be a most satisfying and rewarding experience. The performance of the wrist configuration definitely is indicative of the capability to produce the 15 ft lb torque in either one of the three motions and the smoothness of operation is a pleasure to witness. A demonstration of the unit at a one-day exhibit in Washington D.C. at the Rehabilitation Engineering Conference in early September 1977 also drew several approving comments from a wide variety of interested people.

During the assembly of the wrist, it became quite apparent that several minor changes of some parts can be made in order to make the assembly more easy to accomplish as well as several areas of weight reduction without endangering the overall strength of the unit.

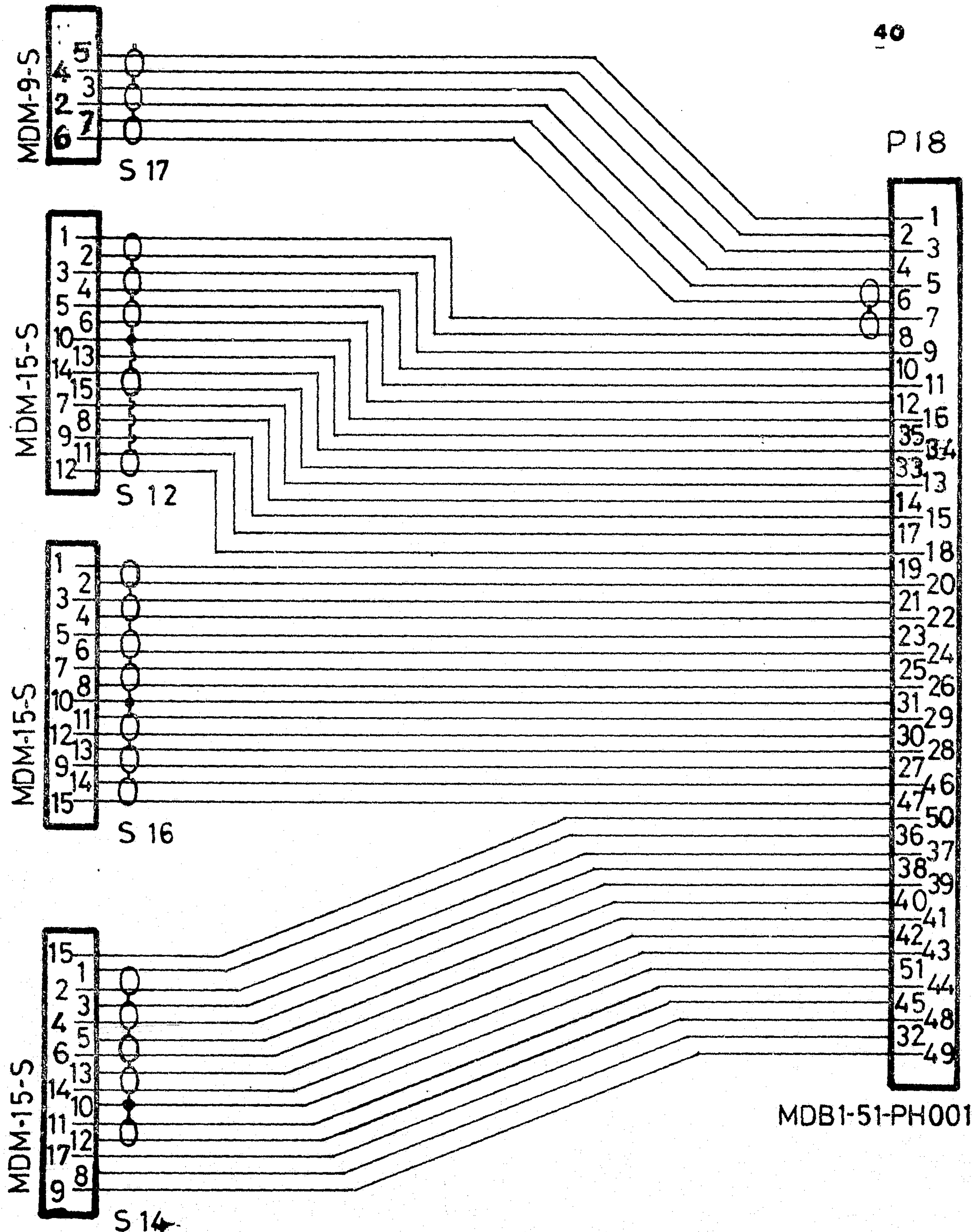
A scaled-up or scaled-down version of this basic structure is also possible, allowing for increased or decreased power output, depending upon the requirement of the manipulator itself.

For non-space applications it should be noted that, if tach generators and resolvers are non-essential to the wrist, the unit can be manufactured with a much shorter overall length. Robotics in industrial applications, driving mechanisms for joints in prostetics, manipulator-type devices in medicine (scanner positioning) etc all seem areas of possible application.

With this report, and the delivery of the unit itself, I hope to have executed the requirements of the contract to the satisfaction of the MSFC personnel. My sincere thanks to all involved and the fine cooperative effort of Mr. J. Dwight Johnston of MSFC.

V <u>Appendix</u> - A

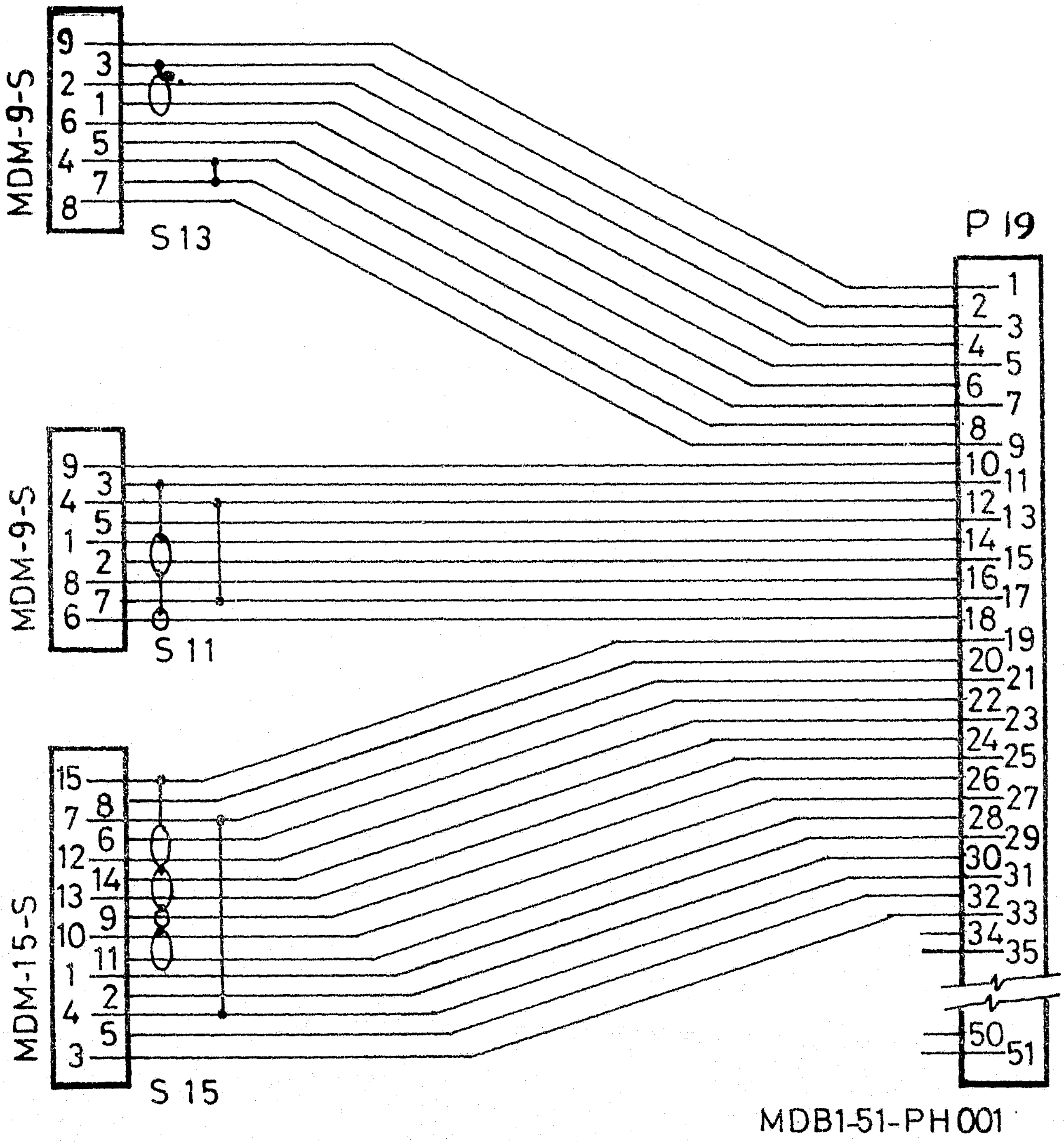
Wiring Diagrams.



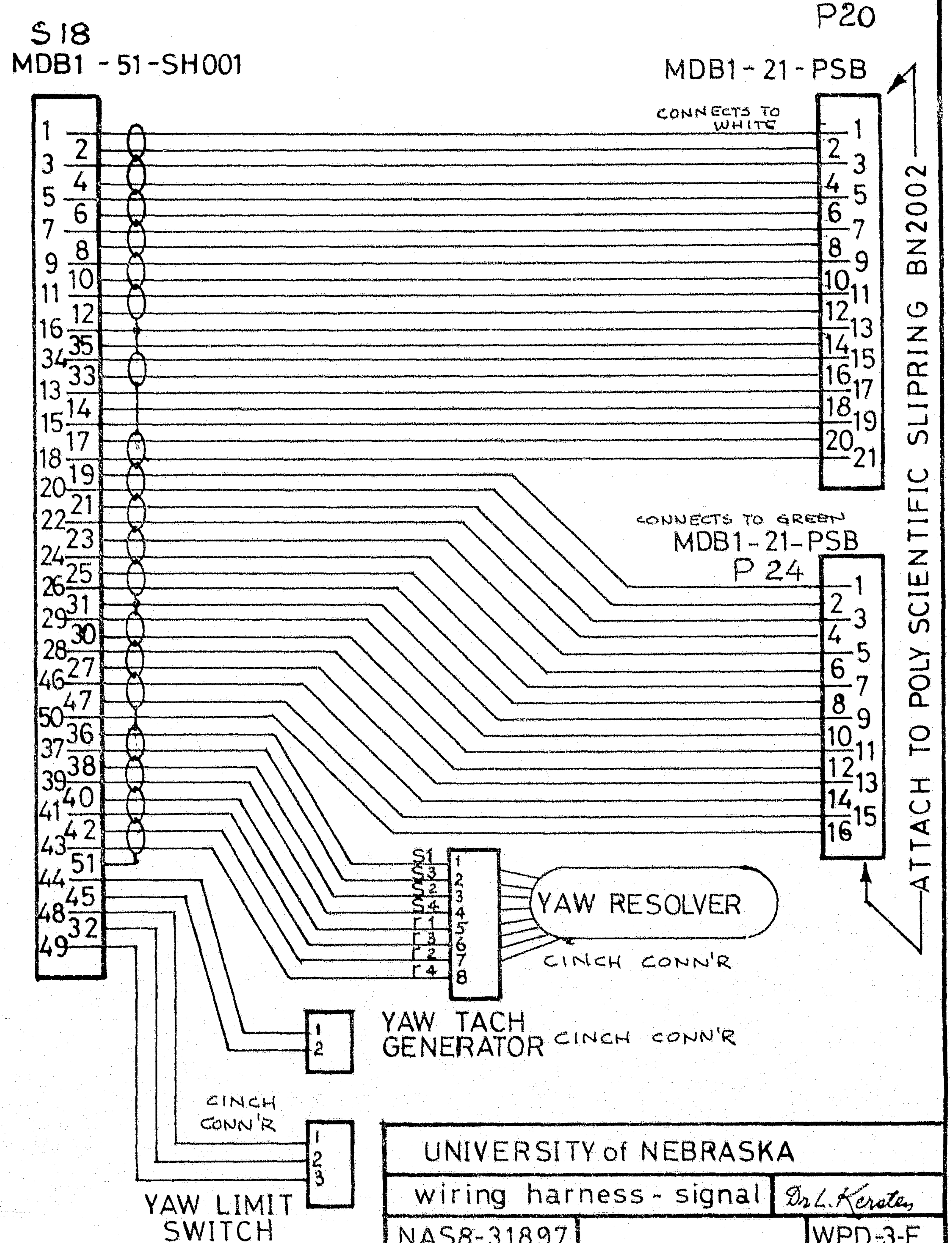
UNIVERSITY of NEBRASKA

wiring harness - signal | Dr L. Kersten

NAS8-31897 | WPD-1-E



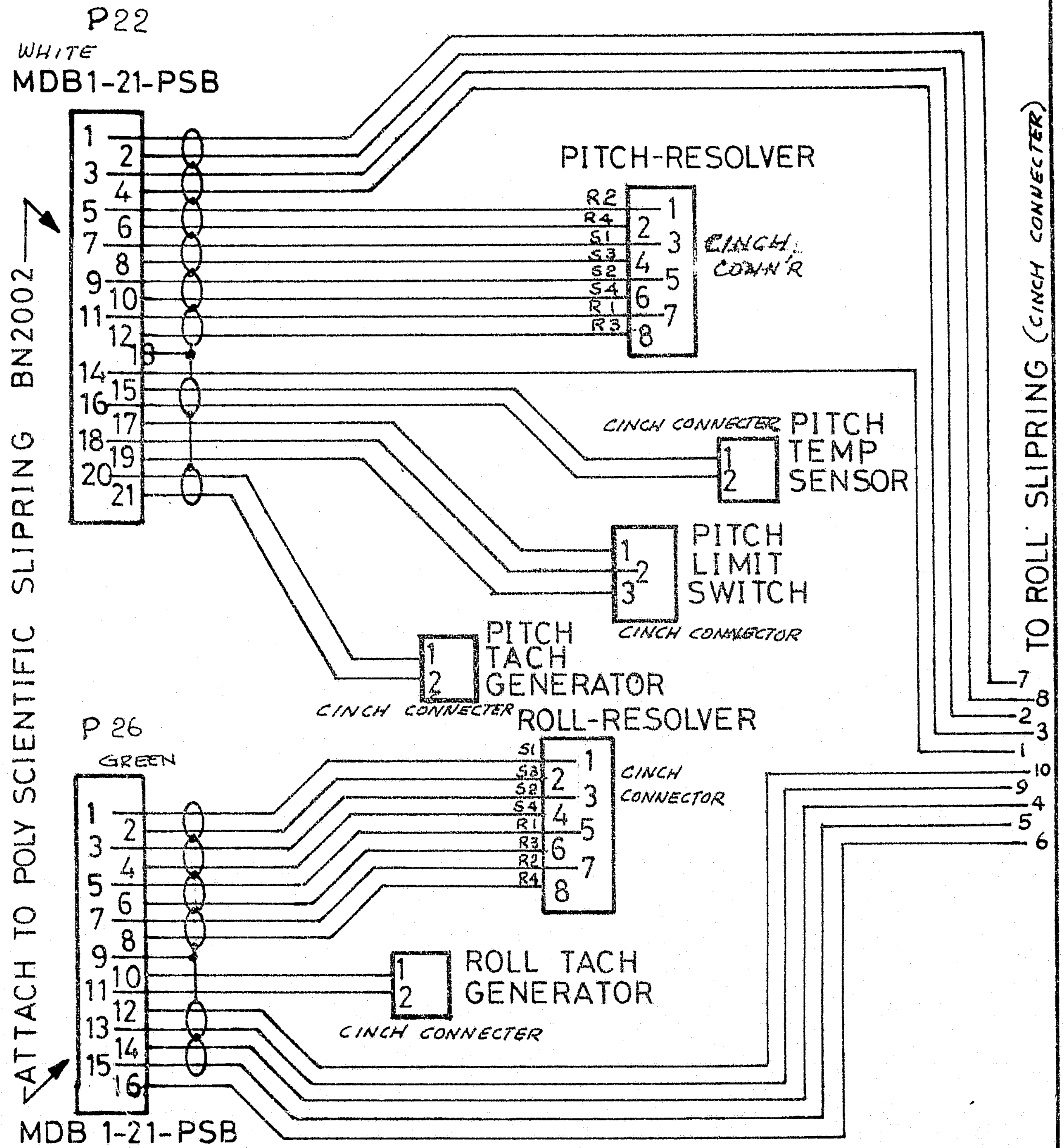
UNIVERSITY of NEBRASKA		
wiring harness - power		Dr L. Kersten
NAS8-31897		WPD-2-E



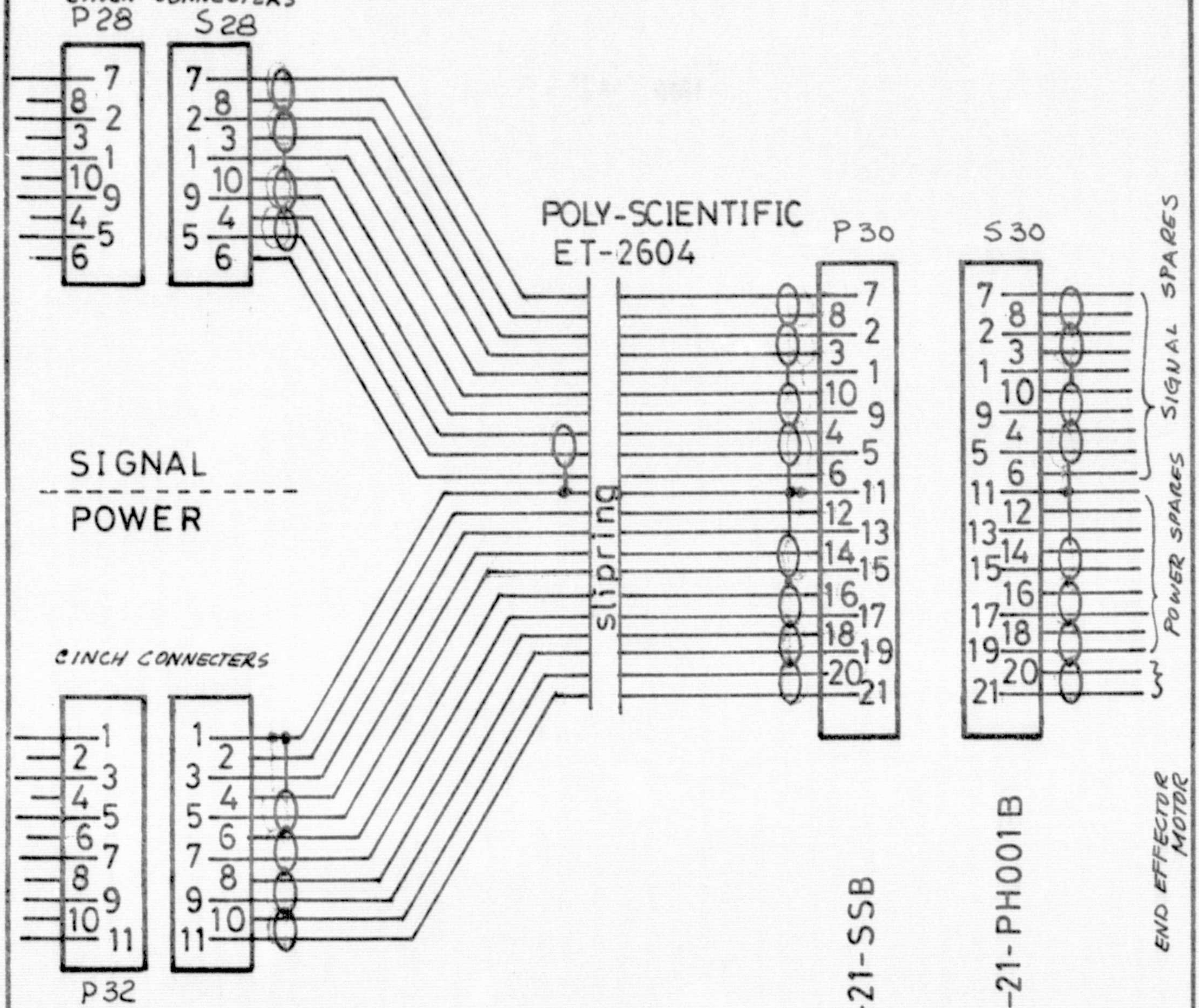
UNIVERSITY of NEBRASKA

wiring harness - signal | Dr L. Kersten

NAS8-31897 | WPD-3-E



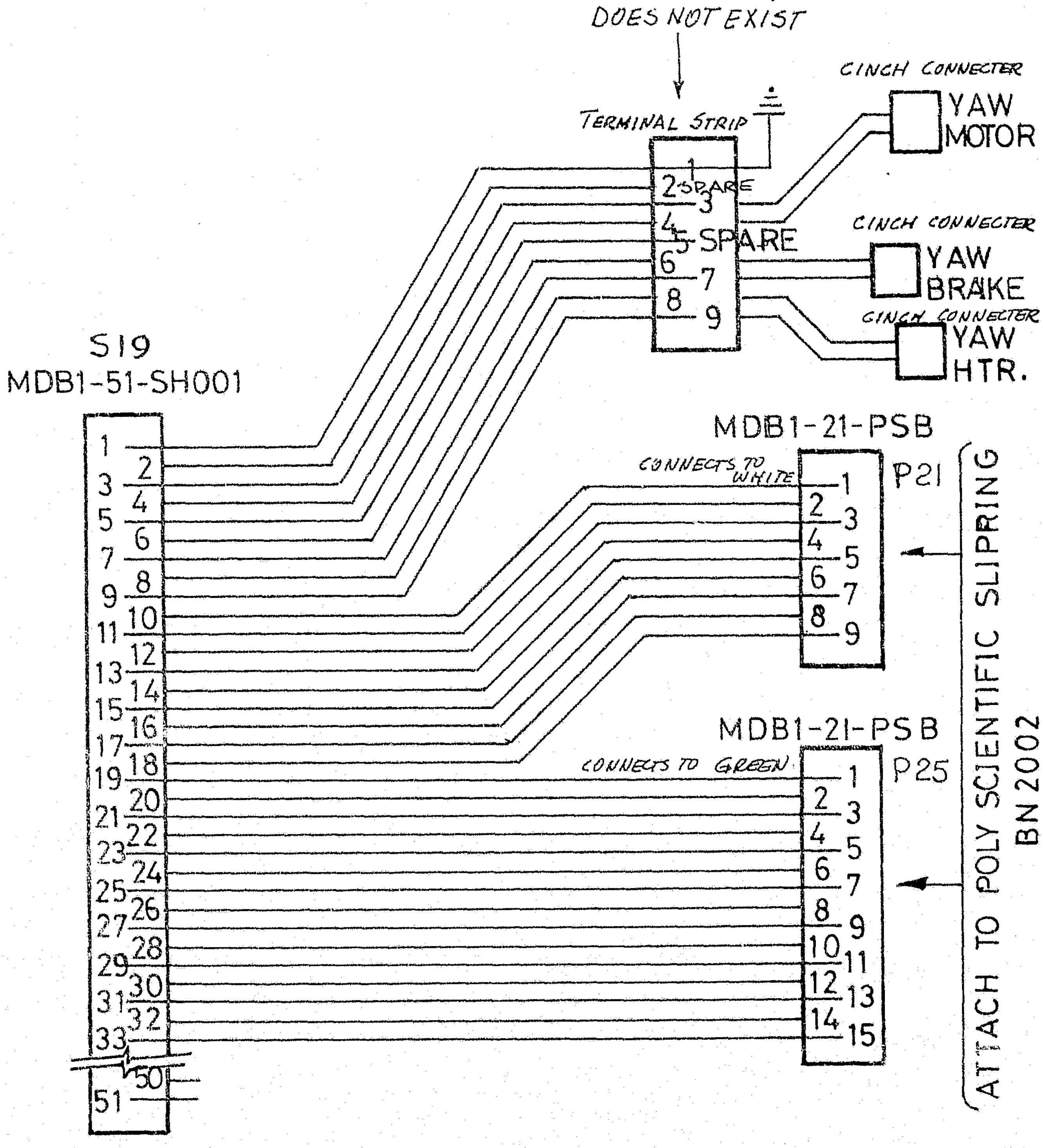
UNIVERSITY of NEBRASKA	
wiring harness - signal	Dr L Kersten
NAS8-31897	WPD-4-E



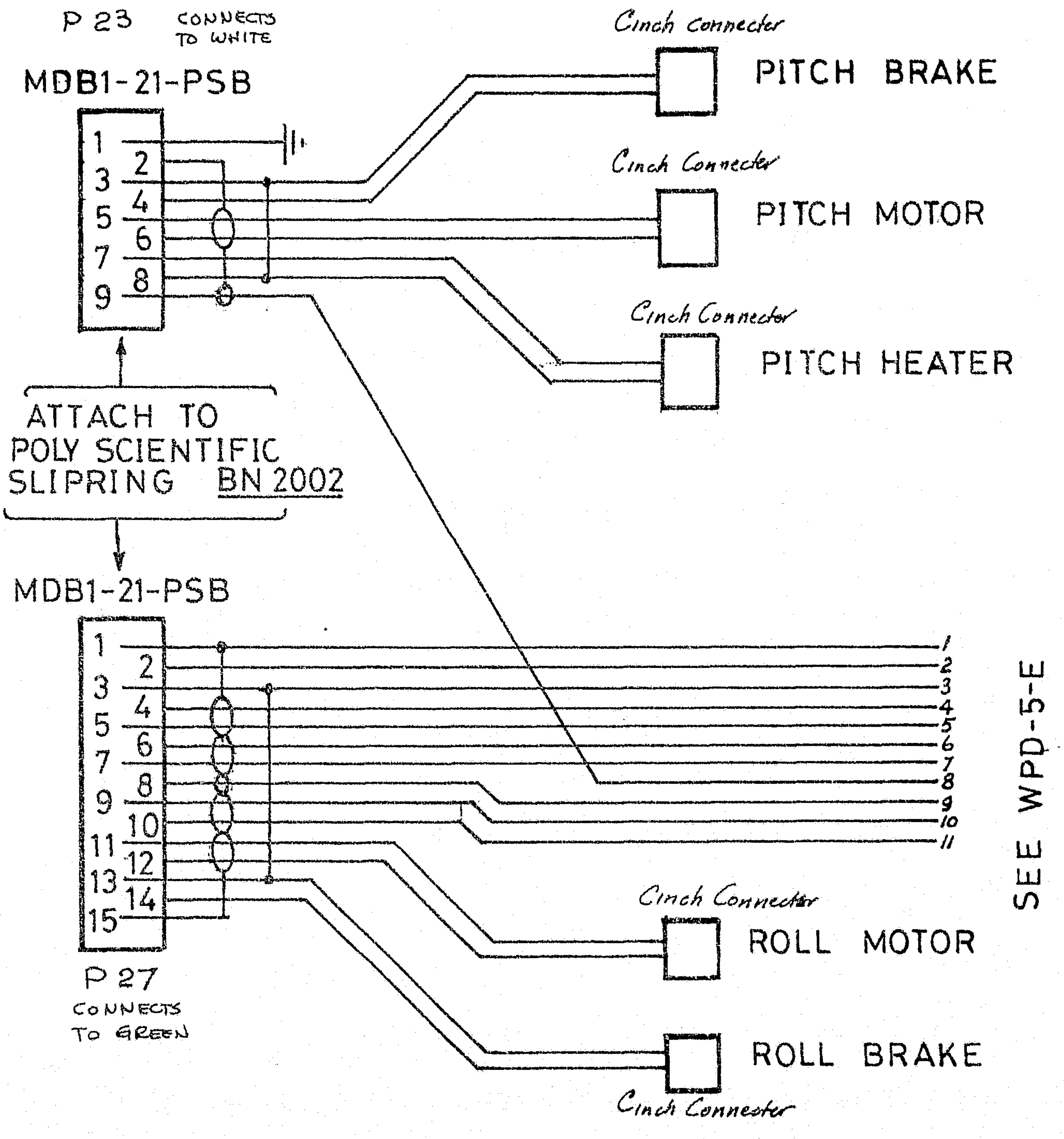
UNIVERSITY of NEBRASKA

wiring harness + signal power — D. L. Kersten

NAS8-31897 — WPD-5-E

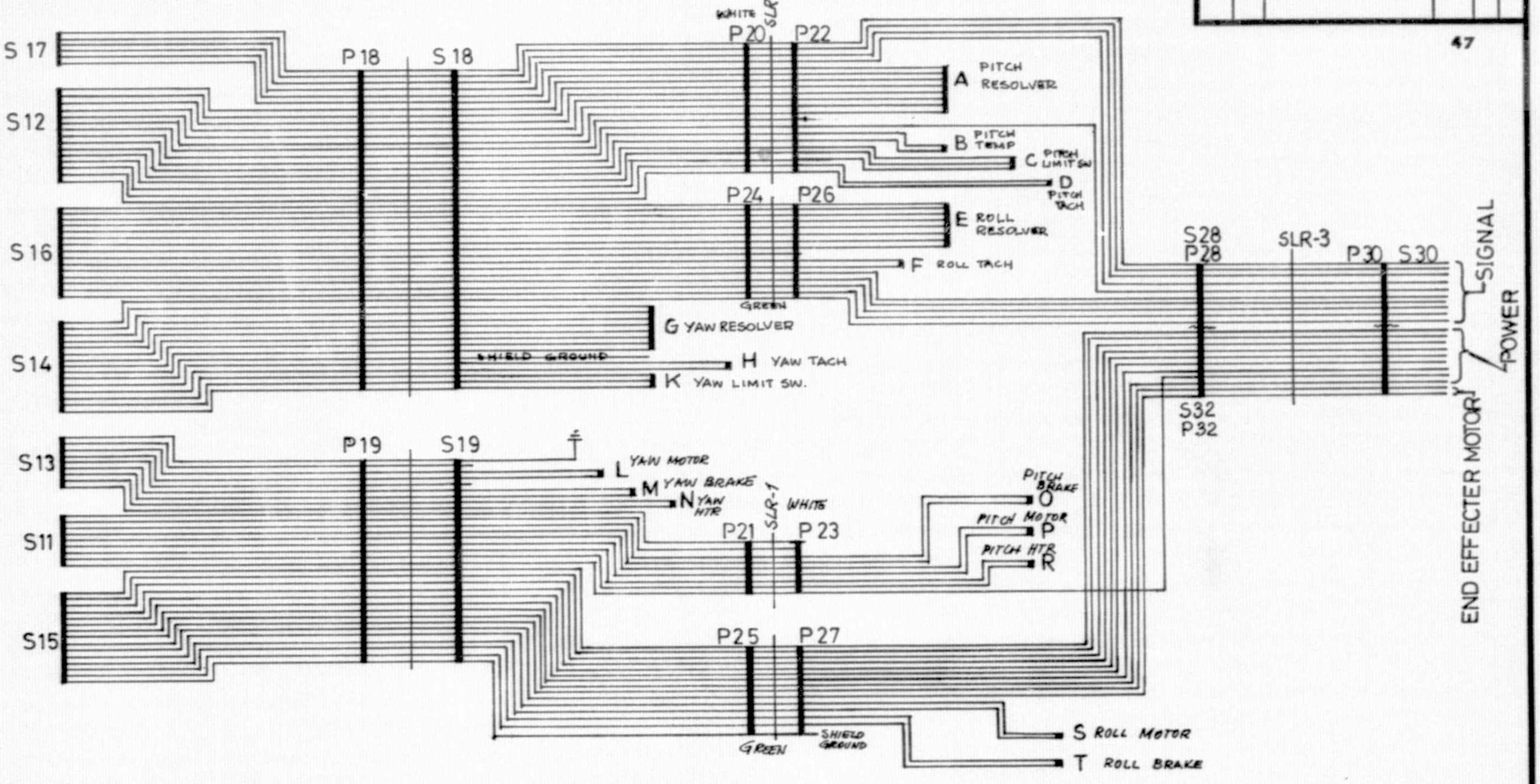


UNIVERSITY of NEBRASKA		
wiring harness - power	Dr L. Kersten	
NAS8-31897		WPD-6-E



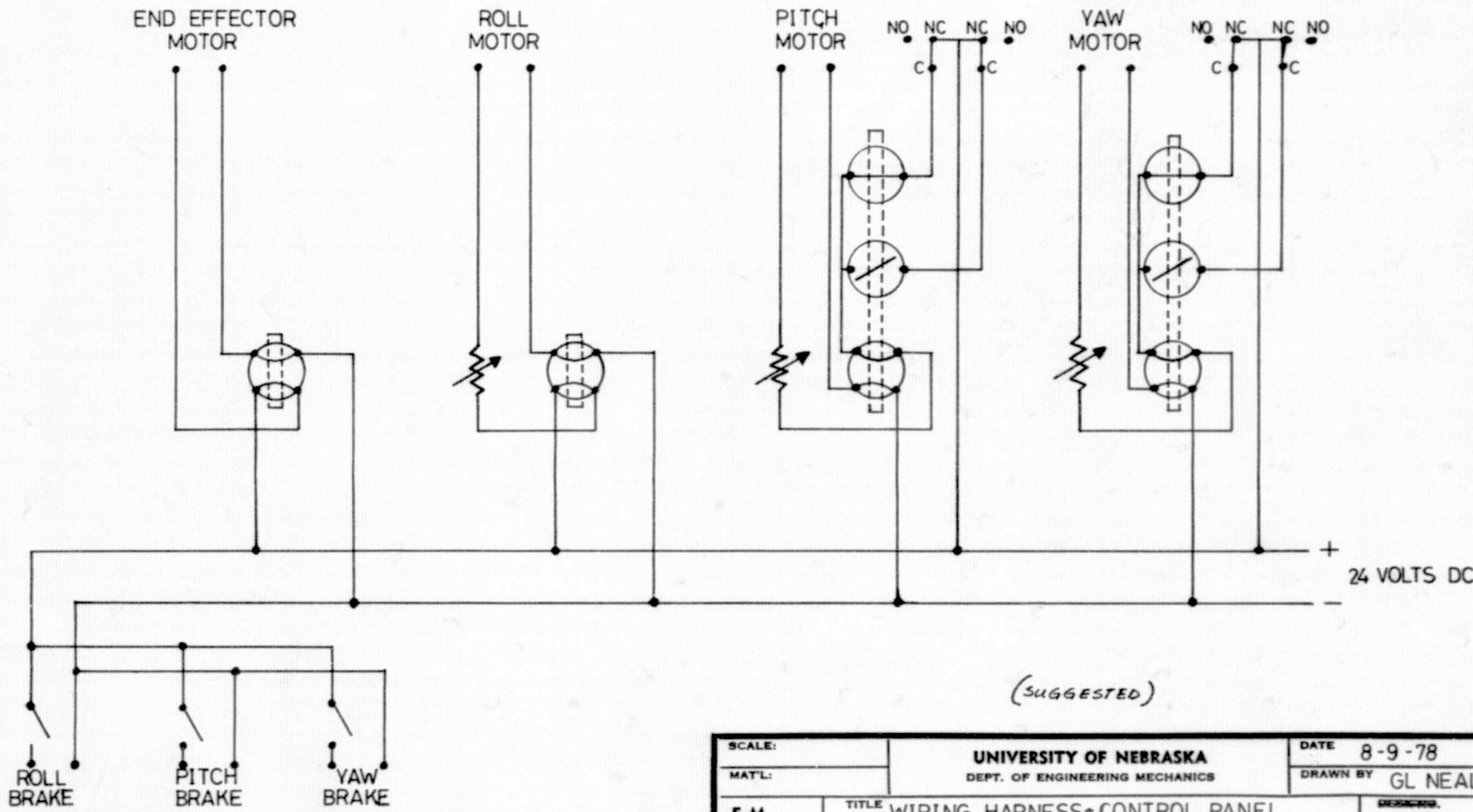
UNIVERSITY of NEBRASKA		
wiring harness – power		D. L. Kersten
NAS8-31897		WPD-7-E

DATE	SYM	REVISION RECORD	AUTH.	DR.	CK.



SCALE:	UNIVERSITY OF NEBRASKA DEPT. OF ENGINEERING MECHANICS	DATE 7/24/78
MAT'L: SEE ALSO PARTS LIST		DRAWN BY G.N.
E.M.	TITLE WIRING DIAGRAM — TACPAW	DESK NO. NAS8-31897

DATE	SYM	REVISION RECORD	AUTH.	DR.	CK.



(SUGGESTED)

SCALE:	UNIVERSITY OF NEBRASKA DEPT. OF ENGINEERING MECHANICS	DATE	8-9-78
MAT'L:		DRAWN BY	GL NEAL
E.M.	TITLE WIRING HARNESS-CONTROL PANEL NAS8-31897		WPD-7-E-X

Appendix - B

Drawing Revisions

WCD-140. The $3.18\phi \pm .02$ 3 holes should become

'4 holes, i.e, through entire hub thickness'

WCD-141. Middle on the right figure. In the lower portion of this figure the dimensions 36.0 and 33.68 should be reversed.

WCD-142. The upper right configuration shows two measurements of 50.0 from the vert. centerline. These should be changed to 45.0 each.

In the lower left of the page, section b-b, a vertical dimension of 16.50 should be changed to 14.50.

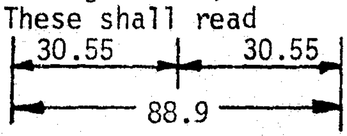
WCD-143. The 4130 STEEL material should be changed to 6061-T6 Aluminum.

WCD-144 (1 of 2). The left figure indicate a 3.2 slot x 7.0 deep, both sides (top). This should have a note to round the sharp edges.

WCD-144 (2 of 2). View c-c indicates a 6-32 UNC-3B hole on the centerline. This one hole shall be replaced by two 10-32 UNC-3B holes at a distance of 10.0 TYP on either side of the vertical centerline.

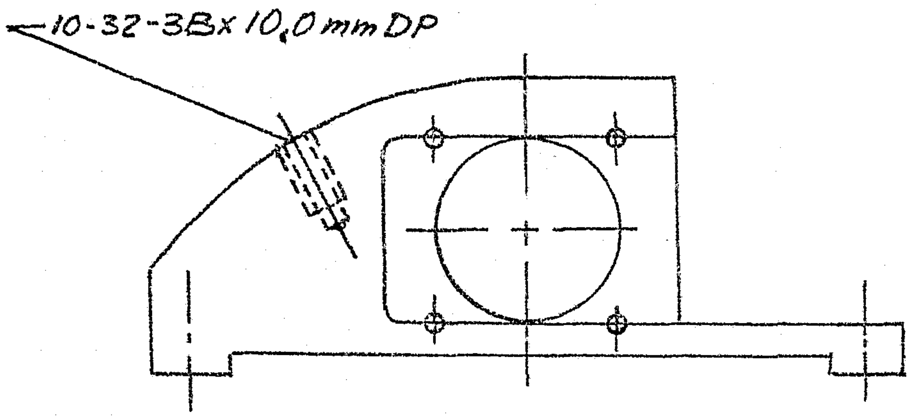
WCD-153. The left view indicates a 2.90ϕ dimension for 5 holes each side. This note must also specify to countersink on the outside for 4-40 flat head screws.

WCD-159. Change mat'l. to 6061-T6 Aluminum. On the upper left view (right side of configuration) three dimensions have been omitted. These shall read



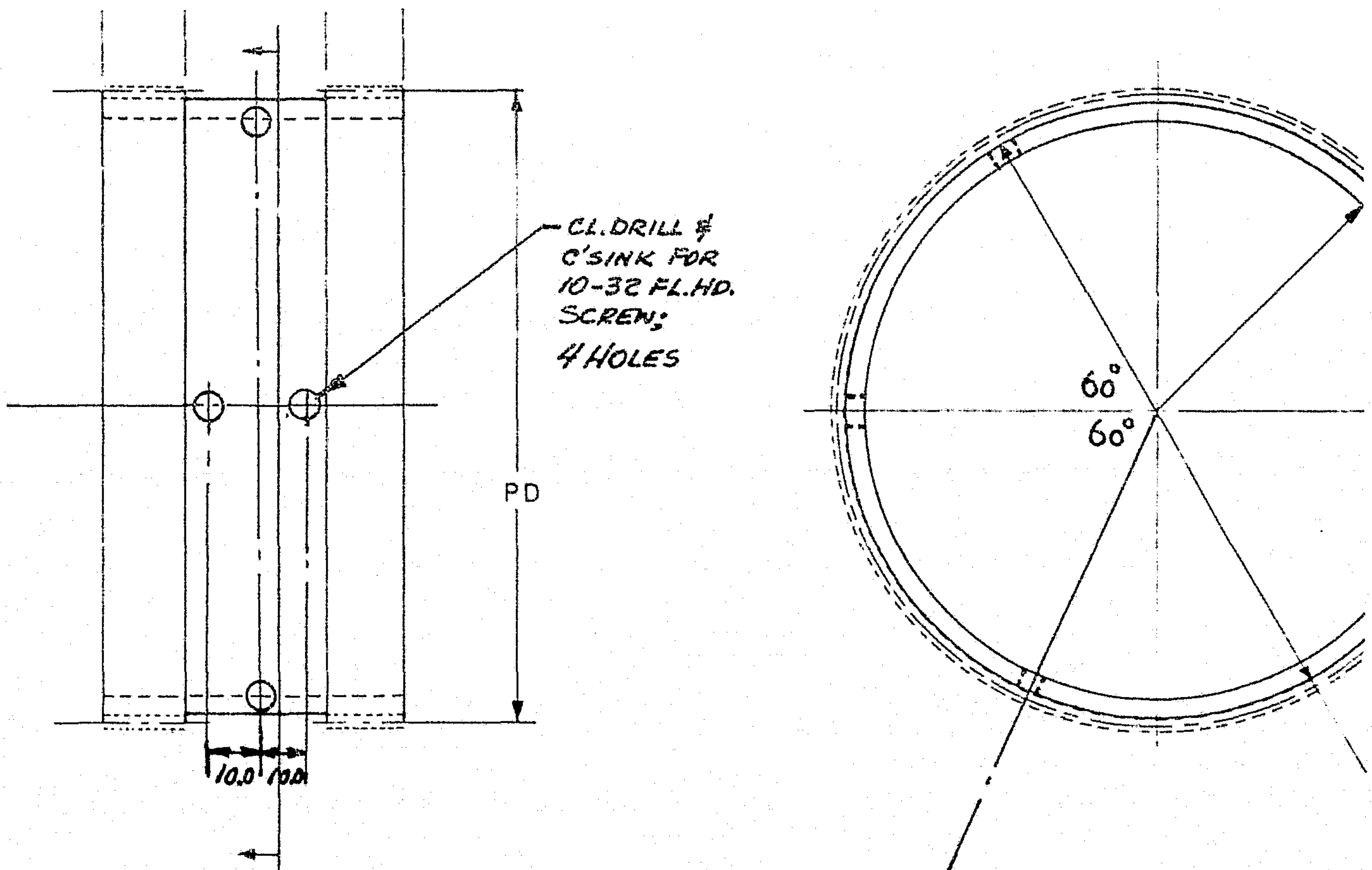
WCD-160. The sectional view does not indicate the tapped hole size on the left. This shall be a 10-32 UNC-3B x 10.0 mm deep.

WCD-161. The upper left drawing shall be altered as shown below. The 4.75ϕ hole in the right side view is to be omitted.

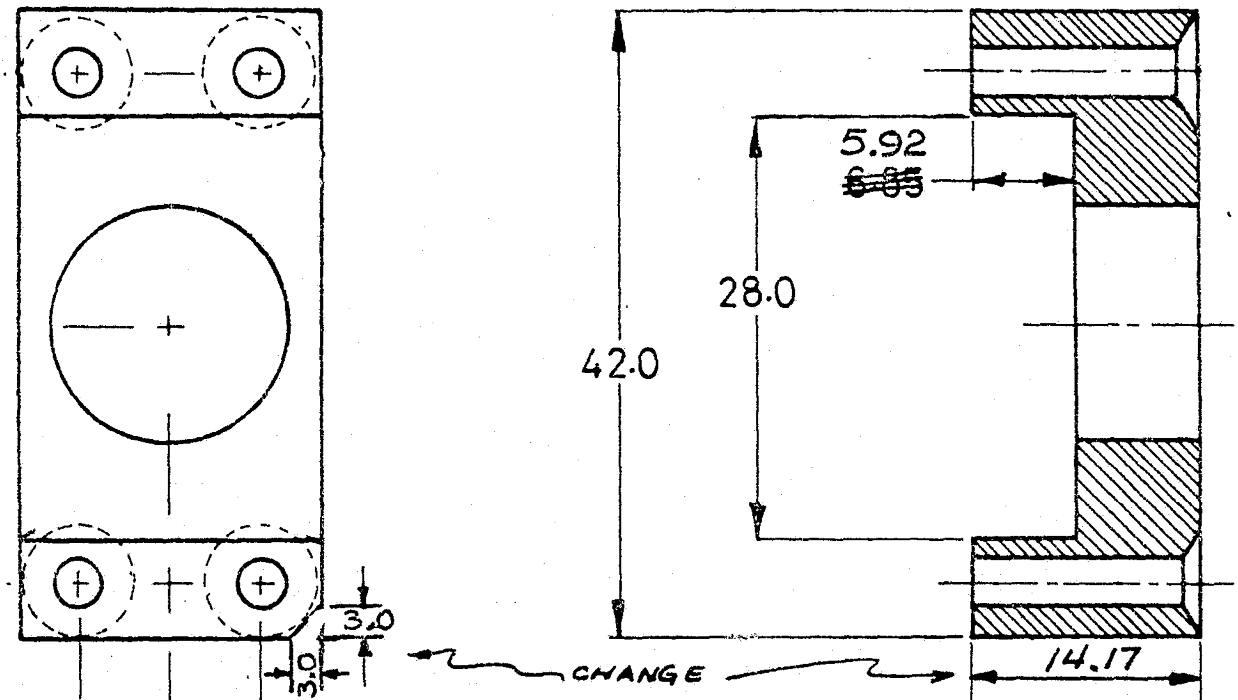


WCD-171. Completely omit this part from the assembly.

WCD-201. Shall be altered as shown below.



WCD-242. Alter the part as shown below.



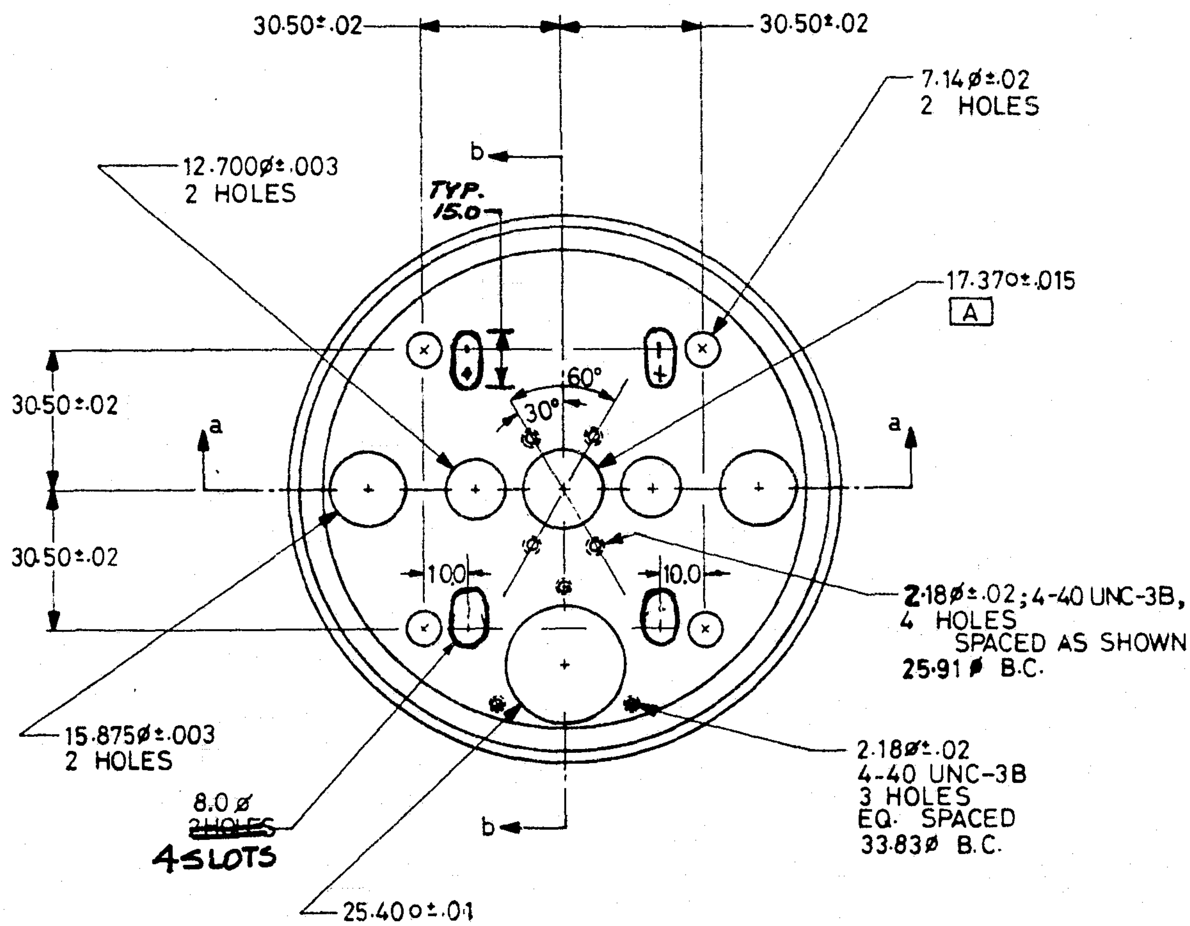
WCD-240. In the middle figure, the lowest placed dimension reads 34.62. This shall be altered to read 33.62.

WCD-241. On the top of the left figure a dimension 15.875 ± .005 appears. This shall be altered to read 17.46 ± .01. On the left of this same figure a vertical dimension measured from the centerline reads 27.496 ± .005. This shall be changed to read 30.24 ± .01.

WCD-260. The left-upper view indicates a 68.0R dimension. This must be changed to read 71.5R.

Likewise, the upper right figure shows a 63.0R which must be changed to 66.5R. In the lower left the 5.50 dimension must be changed to 6.50 whereas the other vertical dimension is 19.14.

WCD-342. The upper left configuration should be altered as indicated below.

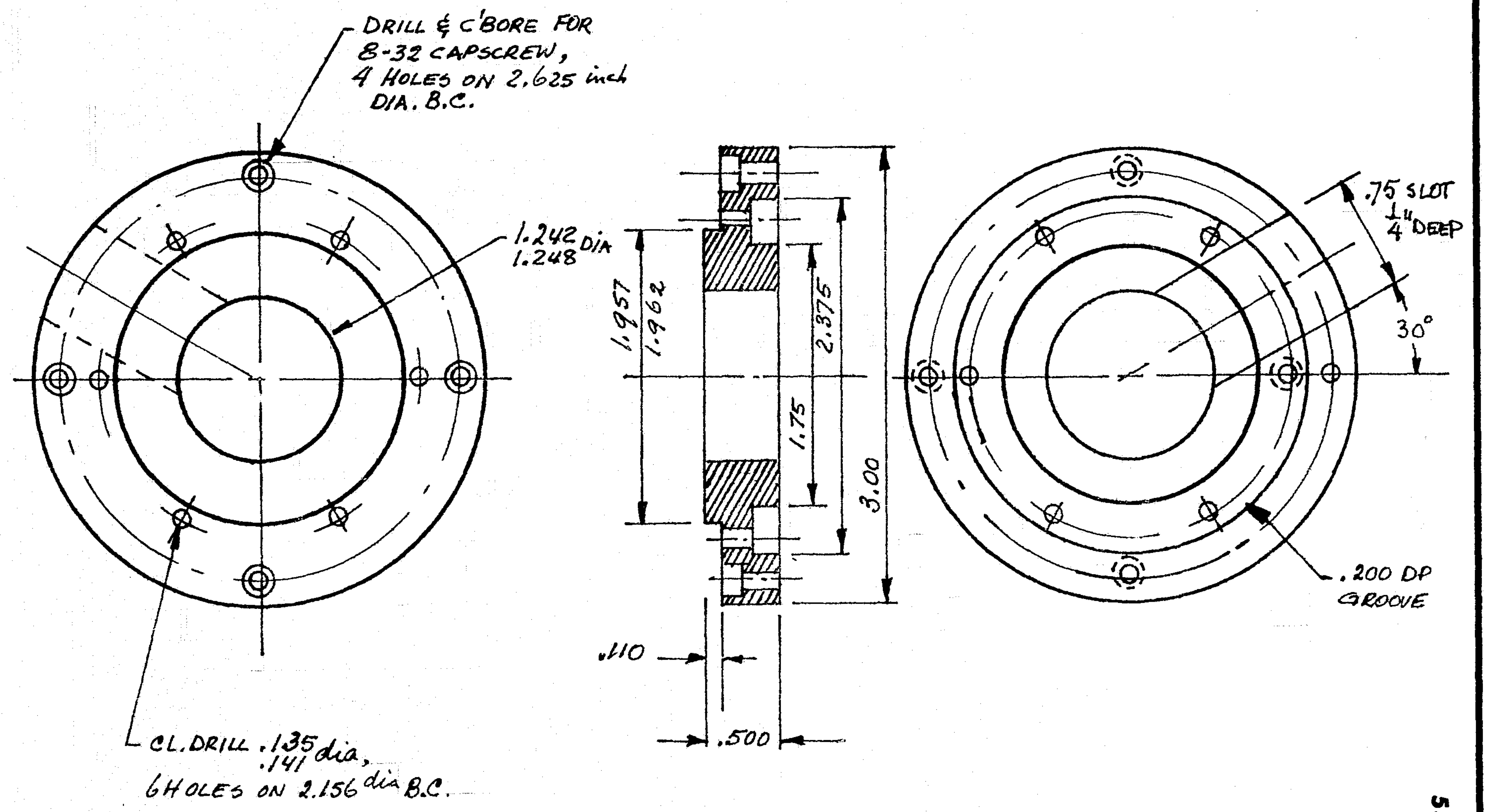


WCD-343. The material shall be changed from 4130 steel to 6061-T6 Aluminum.

WCD-344. Material shall be 6061-T6 Aluminum.

WCD-380. Change material to 6061-T6 Aluminum.

Note: Attached is also an End-Effector Adapter Plate (WCD-XTRA) as it was supplied on the actual prototype TACPAW. It can be seen on the photograph 29.



SCALE FULL	6061 T6 ALUMINUM	END EFFECTOR ADAPTER PLATE (ESAM)	NAME LK — NAS8-31897
DATE 7/21/78			U. OF N. — E. M. — WCD-XTRA

Appendix D

The following pages contain U.S.Patent Nr. 4,068,763 of the Wrist Joint Assembly TACPAW.

Due to the extreme power requirements in all three modes, i.e. pitch, yaw and roll, it was decided to use the Inland torque motors. In principle the TACPAW as fabricated is identical to the TACPAW disclosed in the patent.

United States Patent [19]

Fletcher et al.

[11] 4,068,763

[45] Jan. 17, 1978

[54] **WRIST JOINT ASSEMBLY**

[76] Inventors: **James C. Fletcher,** Administrator of the National Aeronautics and Space Administration, with respect to an invention of; **Leendert Kersten,** Lincoln, Nebr.; **James D. Johnston,** Madison, Ala.

[21] Appl. No.: **708,800**

[22] Filed: **July 26, 1976**

[51] **Int. Cl.**[2] **B25J 3/00**

[52] **U.S. Cl.** .... **214/1 CM;** 3/12.5; 74/515 E

[58] **Field of Search** .... 214/1 CM, 1 BC, 1 BH, 214/1 BD, 1 BV, 147 T, 1 R; 74/515 E; 3/12-12.8

[56] **References Cited**

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3,922,930	12/1975	Fletcher et al.	214/1 CM X

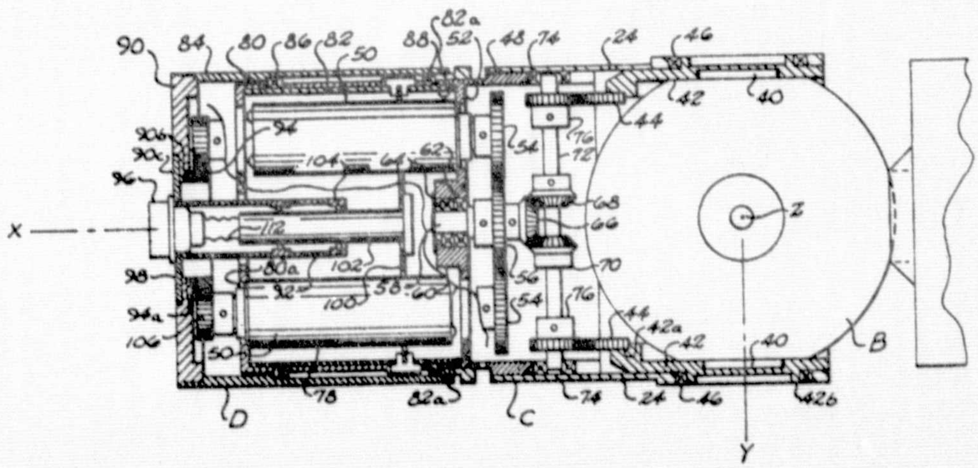
Primary Examiner—Frank E. Werner

Attorney, Agent, or Firm—L. D. Wofford, Jr.; J. H. Beumer; John R. Manning

[57] **ABSTRACT**

A wrist joint assembly is provided for use with a mechanical manipulator arm for finely positioning an end-effector carried by the wrist joint on the terminal end of the manipulator arm wherein the wrist joint assembly is pivotable about a first axis to produce a yaw motion, a second axis to produce a pitch motion, and a third axis to produce a roll motion, wherein the three axes are mutually perpendicular and have a common point of origin. The wrist joint assembly includes a disk segment affixed to the terminal end of the manipulator arm and a first housing member rotatably carried on the disk segment about the first axis. A second housing member is rotatably carried on the first housing member and a third housing member is rotatably carried on the second housing member whereby the third housing member and the mechanical end-effector carried thereon are moved in the yaw, pitch, and roll motion. Drive means are provided for rotating each of the housings about their respective axis which includes a cluster of miniature motors having spur gears carried on the output drive shaft thereof which mesh with a center drive gear affixed on the housing to be rotated.

13 Claims, 9 Drawing Figures



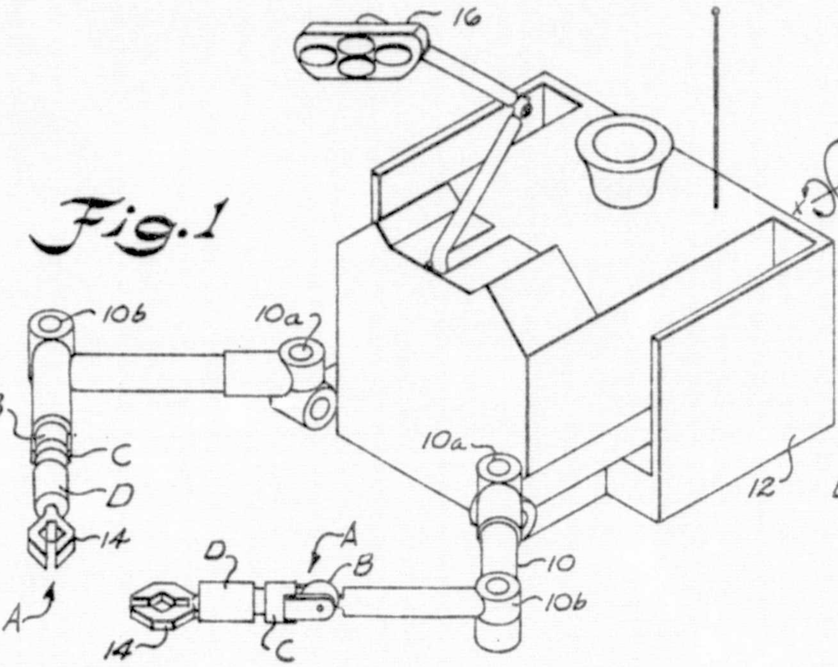


Fig. 1

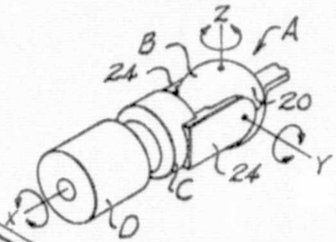


Fig. 1a

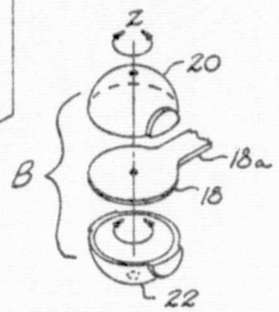


Fig. 1b

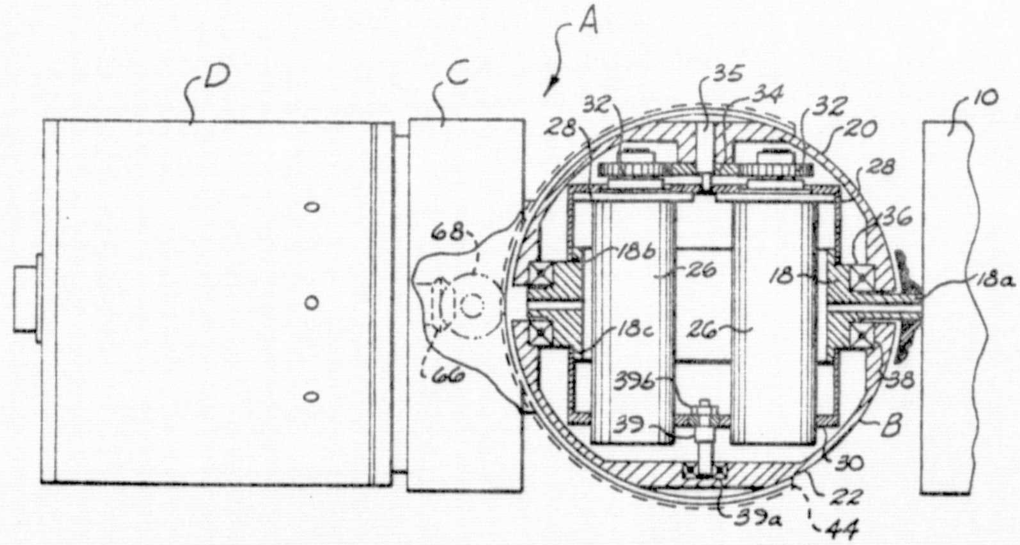
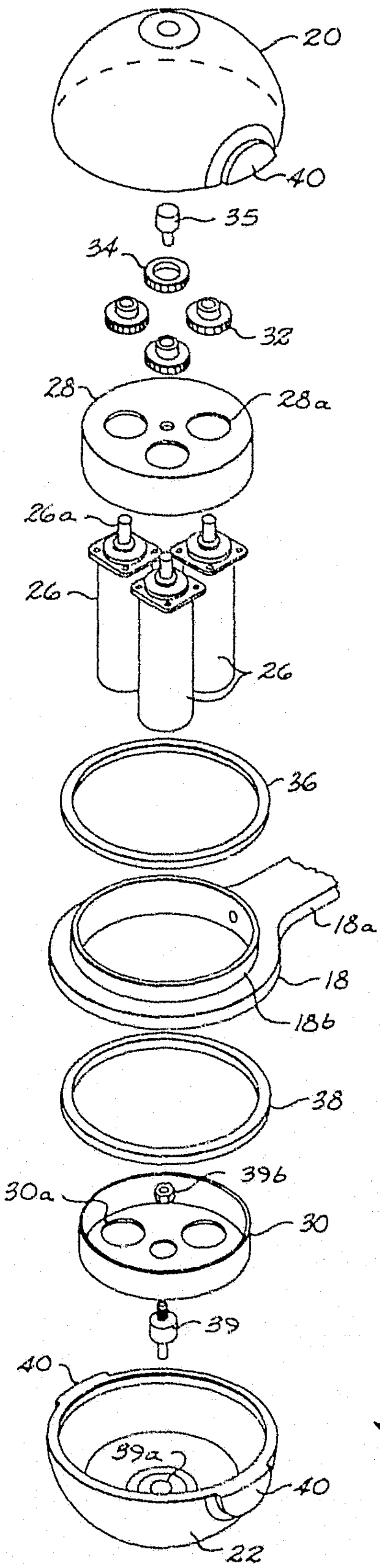


Fig. 3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28a
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22

Fig. 2

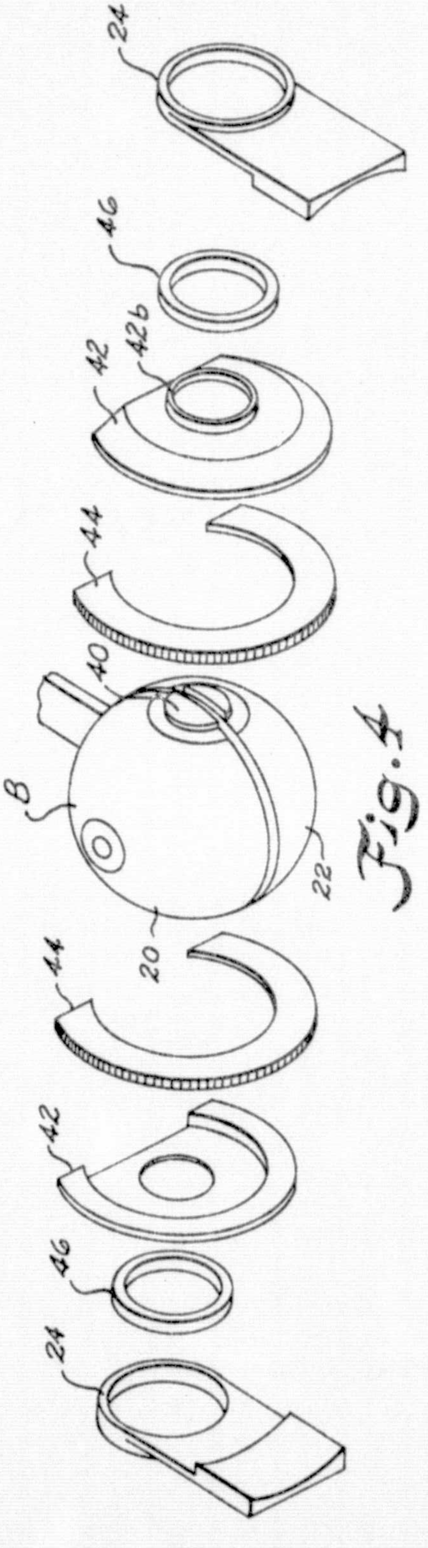


Fig. 4

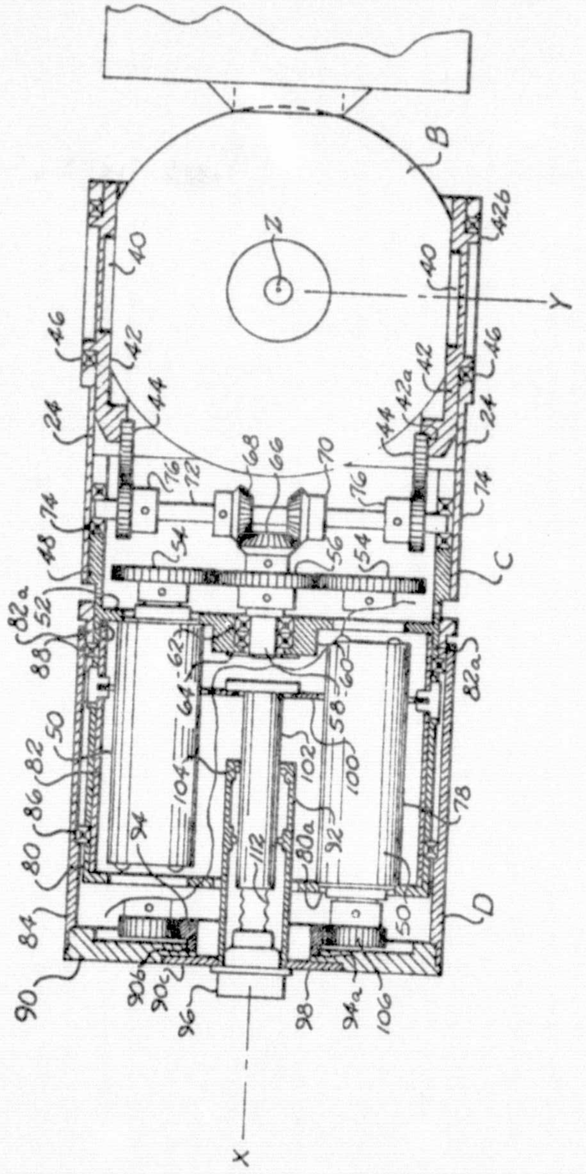
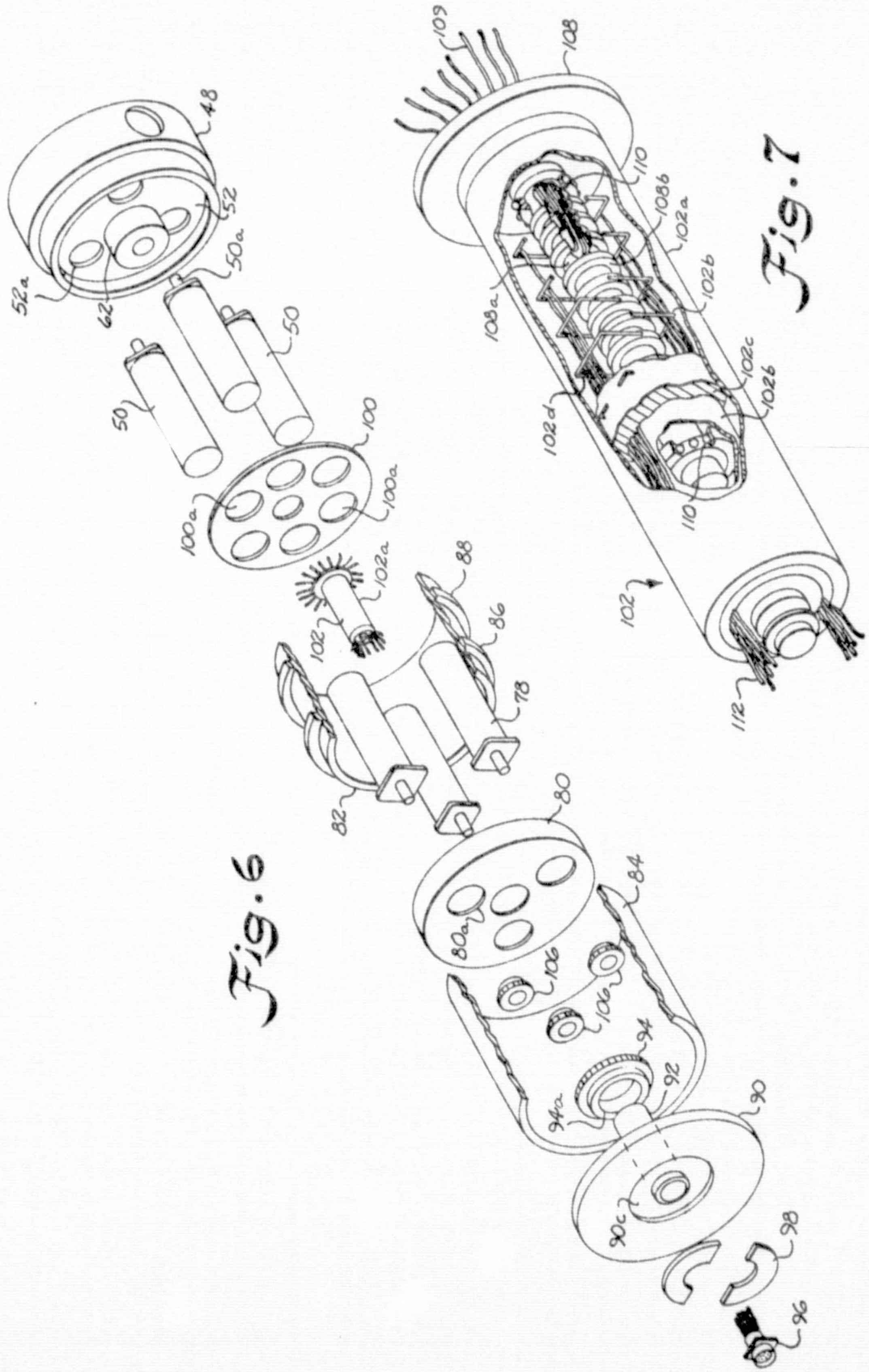


Fig. 5


48
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106
94
92
94a
90
90c
98
96
109
108
110
108b
102a
102b
108a
102c
102b
102d
110
102
112

Fig. 6

Fig. 7

WRIST JOINT ASSEMBLY

ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Art of 1958, Public Law 85-568 (72 Stat. 435; 412 U.S.C.2457).

BACKGROUND OF THE INVENTION

Mechanical manipulator arms terminating in some type of mechanical hand or gripping device (end-effector) are commonly employed on space vehicles for performing planetary explorations, and satellite and space shuttle operations. The manipulator arms and the joints thereof together with the end-effector are usually remotely controlled by a closed-loop guidance system commonly known as a teleoperator. Teleoperators normally include a guidance loop having an electronic eye device such as stereo television and a man in the loop to remotely control the manipulator arm and hand through motorized pivot joints.

During the past several years an increased effort in manipulator design has been directed mainly toward the actual control of the manipulator with or without the attached end-effectors in order to perform special tasks from a remote position. As important as this research is, it should be realized that the degree of control sophistication is directly proportional to the degree of manipulator joint and end-effector sophistication.

It seems that enough effort has not been directed to the design and improvement of the various joints, their drives and their configurations. The practice of present day equipment-designers seems to point to the separation of yaw, pitch and roll motion by physical distances, especially in the wrist joint located at the terminal end of the manipulator arm upon which the end-effector is carried. This practice makes the solution of the mathematical equation, which defines the relative position of the terminal end of the manipulator and which is utilized in the control system, a rather difficult task.

Also, past joint designs have resulted in several configurations of acceptable, small physical shape but which show externally applied drive and several mechanisms. These devices thus nullify the objective of improved visibility around the joint.

For space application the joints with bulky configurations cannot be accepted since many tasks will have to be performed in the "shadow-side" and requiring illumination from sources on the teleoperator. These requirements demand a maximum of visibility.

In many present day designs of manipulator arms the wrist joint configuration has been simplified to the degree that not three but two motions occur in the wrist joint whereas the third motion is supplied by the shoulder of the manipulator arm or is completely ignored altogether. For those arms that have three degrees of freedom in the wrist joint, the actual configurations produce, in some cases, a very bulky joint which does not provide for the required visibility referred to above.

The task at present is to design a wrist joint assembly which is better than what is currently available yet conforms to the rules of sound kinematic manipulator design. The present invention provides such a new device which has been successfully demonstrated.

SUMMARY OF THE INVENTION

The invention relates to a wrist joint assembly used with a mechanical manipulator arm for moving and finely positioning an end-effector such as mechanical hand carried by a wrist joint on the terminal end of the manipulator arm. The wrist joint assembly includes a disk segment having an outwardly extending arm affixed to the terminal end of a manipulator arm, and a first housing member having a pair of shell members rotatably carried on the disk segment. A first drive means is provided for rotating the first housing member about a first axis coinciding with the axis of the disk segment to produce a yaw motion.

A second housing member is rotatably carried by said first housing member pivotable about a second axis extending through the first housing member and normal to the first axis. A second drive means is connected between the second and first housing members for rotating the second housing member about the second axis to produce a pitch motion. The second housing is moved in both the yaw and pitch motions.

A third housing member is rotatably carried by the second housing member about a third axis normal to the plane of the first and second axes so that the first, second and third axis are mutually normal to each other and have a common point of origin. A third drive means is connected between the third and second housings for rotating the third housing about the third axis to produce a roll motion. The third housing member is thus movable in accordance with the yaw, pitch and roll motions to provide for fine positioning of the end-effector carried by the third housing member.

Accordingly, an important object of the present invention is to provide a manipulator arm wrist joint having three degrees of freedom wherein the three degrees are provided about three mutually perpendicular axes of rotation having a common point of rotation.

Another important object of the present invention is the provision of a superior kinematic manipulator design wherein three degrees of freedom are provided in the last manipulator pivot joint which is as close as possible to the end-effector and wherein the last three degrees of freedom are provided about mutually perpendicular axes.

Another important object of the present invention is the provision of a wrist joint configuration for a space vehicle manipulator arm assembly having three degrees of freedom wherein the pitch movement is between plus and minus ninety degrees, the yaw movement is between plus and minus forty-five degrees, and the roll motion of the assembly is continuous.

Still another important object of the present invention is to provide a motor cluster assembly for use in a miniaturized wrist joint assembly which is capable of producing a required torque about each of the rotational axes.

Yet another important object of the present invention is to provide a wrist joint having three-degrees of freedom in rotation which is compact in size and affords a high degree of "see around" visibility to the remote operator of an end-effector carried on the end of the wrist joint.

BRIEF DESCRIPTION OF THE DRAWING

The construction designed to carry out the invention will be hereinafter described, together with other features thereof.

The invention will be more readily understood from a reading of the following specification and by reference to the accompanying drawing forming a part thereof, wherein an example of the invention is shown and wherein:

FIG. 1 is a perspective view illustrating a teleoperator space vehicle having a pair of mechanical manipulator arm assemblies with end-effectors carried on the end thereof:

FIG. 1*a* is a perspective view illustrating a wrist joint assembly constructed in accordance with the present invention;

FIG. 1*b* is an exploded perspective view of a ball socket assembly constructed in accordance with the present invention which is rotatable about a first axis to produce a yaw motion;

FIG. 2 is a exploded perspective view of a yaw motion for a wrist joint assembly constructed in accordance with the present invention;

FIG. 3 is a partial cut-away side elevational view illustrating the motor and gear arrangement for rotating the yaw motion assembly as constructed in accordance with the present invention;

FIG. 4 is an exploded perspective view of the pitch motion assembly of a wrist joint constructed in accordance with the present invention;

FIG 5 is a partial cut-way top plan view illustrating the motor and gear arrangement for the pitch drive assembly for producing the pitch motion in accordance with the present invention and wherein the view includes a second partial cut-away plane to illustrate the motor and gear drive arrangement for the roll drive assembly; and

FIG. 6 is an exploded perspective view illustrating the assembly roll motion constructed in accordance with the present invention; and

FIG. 7 is a partial cut-away perspective view of the slip ring member shown in FIGS. 5 and 6.

DESCRIPTION OF A PREFERRED EMBODIMENT

A wrist joint, designated generally at A, is illustrated for use with a manipulator arm 10 such as on a teleoperator space vehicle 12. The wrist joint A may be utilized with manipulator arms on manned and unmanned space vehicles and other exploratory vehicles for performing space and planetary operators. The wrist joint A provides three degrees of freedom wherein the pitch motion is between plus minus 90°, the yaw motion is between plus and minus 45°, and the roll motion is continuous. An end-effector 14 is carried on the end of the wrist joint A for performing work such as grasping objects and docking. The position of the end-effector is determined by controlling the movement of the wrist joint A, remotely, as viewed from television camera 16.

The concept of a sphere is utilized to provide a fixed, common pivot point wherein the total freedom of motion relative to this point can be observed and formulated. This concept allows a rotation about the Z-axis to produce a yaw, around the Y-axis to produce a pitch, and around the X-axis to produce a roll motion. Three degrees of freedom are provided with the respective axis mutually orthogonal with respect to each other. The axes have a common point of origin at the center of spherical housing B which provides a common point about which each of the three rotational motions occurs.

Another advantage of this concept is the simplification of the mathematical equation which locates the sphere-center with respect to the coordinates of the shoulder joint 10*a* of the teleoperator vehicle. Such a concept lends itself to well defined guidance equations and precise maneuvering of the manipulator arm 10 and the end-effector 14 carried on the remote end of the wrist joint A. This is particularly important where the end-effector is controlled by man through a remote television camera.

To produce the yaw motion, a disk segment 18 having an arm member 18*a* attached to the terminal end of the manipulator arm and hence considered a fixed body, will allow two hemispherical shells 20 and 22 to rotate about the Z-axis which is also the axis of the disk. The two hemispheres 20 and 22 define a spherical housing member B within which the drive and gear mechanism are housed for effecting the yaw motion.

Another housing member C is made to rotate about the sphere B. The motion of pitch is derived by providing a pivot axis Y for the pitch motion. The pitch axis Y extends through the housing B and a pair of spaced arms 24 which are integral with the housing C so as to pivotably carry the shell C about the pivot axis.

The yaw and pitch motions have rotation axes which are at right angles to each other. To obtain the third axis at ninety degrees, a housing member D rotates about the shell member C to provide the required roll motion about the X-axis.

The drive assemblies for effecting the required rotation will now be described for a preferred embodiment. A torque of fifteen foot pounds is required per axis of rotation to adequately perform work with the end-effector 14.

Since a fifteen foot pound torque requirement is a rather demanding one, a DC motor with the lowest possible weight and highest order of driving torgue is required. One suitable motor is a DC motor Model No. A-2030 manufactured by the Globe Company. This motor is capable of producing a twelve hundred and fifty inch ounce torque which is 6.45 foot pounds. If three motors are clustered together to drive a central shaft and gear, the resultant torque output will be 19.35 foot pounds. This will be adequate to produce fifteen foot pounds torque under eighty percent of peak operating conditions. The total weight of each cluster of three motors is approximately thirty ounces which is very small for the amount of torque generated.

A yaw motion drive means is illustrated in the exploded parts assembly of FIG. 2. The drive means includes three motors 26 which are mounted within an upper cup member 28 and a lower cup member 30 which are, in turn, attached to the disk section 18 which is in the form of a center ring. The mounting cups 28 and 30 are respectively attached, such as by welding, to an upper and lower flange portion 18*b* and 18*c* of the disk segment 18. The motors are mounted within openings 28*a* and 30*a* and may be affixed in any suitable manner such as by spot welding. A plurality of spur gears 32 are carried on the motor output shafts 26*a* and mesh with a center gear 34 which is integrally attached to the upper hemisphere 20 by way of shaft 35 affixed to both. The gear 34 and upper hemisphere 20 rotate with respect to the center ring 18 about flange portion 18*b* through a bearing 36.

In a similar manner the lower hemisphere 22 rotates with respect to the center ring 18 on a bearing 38. Hence, with a center ring 18 affixed to the manipulator arm 10, which makes mounting cups 28 and 30 and the motors 26 fixed, the upper hemisphere 20 is permitted to rotate and provide the yaw motion.

The lower mounting cup 30 is also supported within shell 22 by means of a shaft 39 rotatably received in a bearing 39*a* and affixed to cup 30 by a nut 39*b*. The lower hemisphere 22 also rotates when connected to 20 as will be more fully explained hereinafter.

The spur gears 32 and the center gear 34 may be any suitable gear such as Berg gears P24S32-24 and F24S6-24, respectively.

A pair of raised hub portions 40 are defined on opposing sides of the spherical housing B when the hemispheres 20 and 22 are fitted on the disk segment 18. The raised hub portions 40 are provided for pivotably carrying a pitch motion assembly as is shown in the exploded view of FIG. 4. The pitch assembly includes a pair of side mounting plates 42 which are rigidly affixed over the raised hub portions 40 of the spherical shell B. Integrally attached to each side plate 42 such as by welding at recess 42*a*, is a ring gear segment 44. The side plates 42 and gear ring 44 are thus integrally affixed to raised hub portion 40 of the housing B. The arms 24 are rotatably mounted on flanges 42*b* of the plates 42 and rotate on bearings 46 in a pitch motion relative to the yaw housing B.

The raised hub portion 40 is defined by two half-circle shaped portions each of which is carried on the upper and lower hemispheres 20 and 22. It will be noted that the hemispheres are locked onto the disk segment when the side plates 42 are fitted over the entire circular hub portion 40 defined when the hemispheres are fitted together. In this manner, hemisphere 22 rotates on bearing 38 when hemisphere 20 rotates.

A drive means for driving the pitch motion assembly thus described will now be disclosed as illustrated in FIGS. 4 and 5. The housing C includes a gear housing 48 for enclosing the pitch motion drive assembly and includes spaced arms 24 integral therewith. Within the gear housing 48 is a cluster of three motors 50. The motors are mounted within an assembly cap 52 which is made integral with the housing 48. Three spur gears 54 are carried on the respective output drive shafts 50*a* of the motors 50 extending through openings 52*a* of cap 52. The three spur gears 54 mesh with and drive a center gear 56 which is attached to a central shaft 58. The shaft is journaled within a bearing 60 carried within a recessed portion 62 of the assembly cap member 52. Shaft 58 is maintained within the recess 62 by means of a keeper plate 64. A suitable gear for spur gears 54 and center gear 56 is Berg gear no. P20S35-30.

Also carried on shaft 58 in front of central gear 56 is a bevel gear 66 which drives another bevel gear 68. To prevent side loading and thus bending of the shaft 58, an idler bevel gear 70 is also provided. The bevel gears 68 and 70 are affixed to a shaft 72 which rotates in bearings 74. A pair of gears 76 (Berg gear no. P20S33-20) are fixedly carried adjacent opposing ends of the shaft 72 and mesh with the ring gear segments 44 so that the spaced arms 24 will rotate on bearings 46 and housing B. Hence, the gear housing 48 will rotate in a pitch motion relative to the spherical wrist ball B. The three bevel gears 66, 68, and 70 are preferably a matched set such as gear set M32P-6 manufactured by the Berg Co.

A roll motion drive means is illustrated in the exploded drive assembly of FIG. 6. It can be seen that the spacing of the three motors 50 allows for positioning of three other motors 78 which face in the opposite direction. A motor mounting cap 80, in which the motors 78 are mounted in openings 80*a* in any suitable manner, is rigidly connected to one end of a housing sleeve 82. This housing 82 is attached to the gear housing 48, such as by welding at 82*a*, and constitutes a fixed sleeve portion or extension of housing 48 which is movable in yaw as well as pitch rotation.

The roll housing D is provided by a cylindrical housing 84 rotatably carried on bearings 86 and 88 and rotates about the housing sleeve 82. An end cap 90 is affixed to the end of housing 82 having a central opening 90*a* formed therein through which a tubular guide shaft 92 extends. A central driven gear 94 is affixed to the end cap 90 which as by press fitting a flange portion 94*a* within recess 90*b*. The shaft 92 is affixed to the end cap member 90 by means of an end connector cap 96 and hence rotates with gear 94 and housing 84. A connector mounting plate 98, which fits within recess 90*c*, receives the connector cap 96 therethrough for making connection with the shaft 92. All of the parts may be joined by welding.

A ring plate 100 is provided with a plurality of holes 100*a* for encasing and additionally supporting the six motors including cluster 50 and cluster 78. The ring plate 100 also provides a mounting plate for a special slip ring member 102. The tubular shaft 92 is mounted upon the outer casing 102*a* of the slip ring 102 through O-rings 104. Thus, when the motors 78 are driven, spur gears 106 carried on the output drive shaft of the motors and meshing with the driven gear 94 will cause the driven gear 94 to rotate. This, in turn, will cause the housing 84 and shaft 92 to rotate as well as all of the assemblies that are attached thereto. In this manner the roll motion is provided.

The slip ring member 102, shown in more detail in FIG. 7, includes a flange 108 which is affixed to plate 100. A spindle 108*a* is integrally affixed to flange 108 and includes a plurality of conductive rings 108*b*. Power is supplied to the rings in a conventional manner through wires 109. An outer casing 102*a* rotates on the spindle 108*a* through bearings 110 and includes an inner layer 102*b* adjacent the bearings, and an outer layer 102*c* in which is embedded a plurality of brushes 102*d* which wipe the rings 108*b* in electrical contact as the casing rotates. A plurality of conductor wires 112, which carry the electrical power or signal from the brushes to the end-effector 14, are also embedded in the outer layer 102*c*.

It is noted that the tubular shaft 92 rotates the slip ring outer casing 102*a* by means of a friction drive provided by the pair of flexible O-rings 104. The O-rings may be any suitable resilient material such as rubber and such provides an expedient drive means for the slip ring 102 which is highly sensitive to bending and other forces which would possibly be encountered by a rigid connection between shaft 92 and outer casing 108*a*. Suitable slip ring members are manufactured by the Poly-Scientific division of Litton Industries as shown in slip ring catalog no. 75.

The end cap 96 may be provided with a suitable plug which can be connected to an electrical connector of the end-effector 14 carried on the end of housing 82 in a conventional manner. In this manner, signal and power transmission is provided to the end-effector while the wrist joint operates in a continuous roll manner.

The driven gear 94 and the driving spur gears 106 of the roll drive assembly may be any suitable gears such as Berg gears F20S20-40 and P20S33-15, respectively.

The cluster of motors **78** are preferably the same type motors **26** as used in the yaw drive assembly. All of the motor clusters are furnished power and control signals in a conventional manner from the remote teleoperator.

Thus, an advantageous construction for a wrist joint assembly can be had in accordance with the present invention which is capable of supplying a required torque on each of the three axes of rotation. The wrist joint construction provides structural integrity as compared to the relatively weak wrist joints in the prior manipulator designs while avoiding a bulky joint and improving the "see-around" visibility thereof. By utilizing a cluster of three gear train motors for supplying the drive to each axis of rotation, a triple redundancy is provided in case one of the motors fails.

While a preferred embodiment of the invention has been described using specific terms, such description is for illustrative purposes only, and it is to be understood that changes and variations may be made without departing from the spirit or scope of the following claims.

What is claimed is:

1. A wrist joint assembly for use with a mechanical manipulator arm for moving and finely positioning an end-effector carried by said wrist joint on the terminal end of said manipulator arm, said wrist joint assembly comprising:

- a disk segment having an outwardly extending arm affixed to the terminal end of said manipulator arm;
- a first housing member rotatably carried on said disk segment;
- first drive means connected between said first housing member and said disk segment for rotating said first housing member about a first axis coinciding with the axis of said disk segment to produce a yaw motion;
- a second housing member carried by said first housing member pivotable about a second axis normal to and intersecting said first axis.
- second drive means connected between said second and first housings for rotating said second housing member about said second axis to produce a pitch motion, said second housing being movable in both said yaw and pitch motions;
- a third housing member rotatably carried by said second housing about a third axis normal to the plane of said first and second axes so that said first, second, and third axis are mutually normal to each other and have a common point of origin;
- third drive means connected between said third and second housings for rotating said third housing about said third axis to produce a roll motion; and
- said third housing being movable in accordance with said yaw, pitch, and roll motions to provide for fine positioning of said end-effector carried by said third housing.

2. The assembly as set forth in claim **1** wherein said first housing member includes a raised hub portion on the opposing sides thereof, said second housing member including a pair of spaced arm members pivotably carried on said hub portions.

3. The assembly as set forth in claim **2** wherein said second drive means includes first gear means affixed to said hub portions and second gear means carried by said second housing member in meshing relationship with said first gear means, said spaced arm members being rotatably carried on said first gear means, and motor means for rotating said second gear means so as to cause

said spaced arm members to rotate about said first gear means and said raised hub portions.

4. The assembly as set forth in claim **3** wherein said second gear means includes a shaft rotatably carried by said second housing member, a drive gear carried on said shaft for rotation therewith and meshing with said first gear means, a first bevel gear carried on said shaft for rotation therewith, a second shaft rotatably carried by said second housing having a second bevel gear affixed thereto in meshing relationship with said first bevel gear, and said second shaft being rotated by said motor means.

5. The assembly as set forth in claim **1** wherein said third housing member is rotatably carried about a fixed sleeve portion of said second housing member and rotates thereon.

6. The assembly as set forth in claim **5** wherein said third drive means includes a center gear connected to said third housing member, motor means carried within said sleeve portion having a drive gear means carried on an output drive shaft thereof in meshing relationship with said center gear.

7. The assembly as set forth in claim **5** wherein said assembly further comprises a slip ring member connected between said second and third housing members for providing signal and power transmission to said end-effector carried by said third housing member while said third housing member is movable in a continuous roll motion.

8. The assembly as set forth in claim **1** wherein said first drive means includes a center gear affixed to said first housing member, motor means carried within said first housing member, and drive gear means carried on an output shaft of said motor means meshing with said center gear for rotating said first housing member about said disk segment.

9. The assembly as set forth in claim **1** wherein said first housing member includes a pair of hemispherical shell members rotatably carried on opposing sides of said disk segment to define a spherical ball socket assembly for housing said first drive means.

10. A wrist joint assembly for use with a mechanical manipulator arm for positioning an end-effector carried by said wrist joint on the terminal end of said manipulator arm, said wrist joint assembly being pivotable about a first axis to produce a yaw motion, a second axis to produce a pitch motion, and a third axis to produce a roll motion, wherein said first, second, and third axes are mutually perpendicular to each other and have a common point of origin, said wrist joint assembly comprising:

- a disk segment having an outwardly extending arm fixed to the terminal end of said manipulator arm;
- a first housing member rotatably carried on said disk segment about said first axis, first drive means for rotating said first housing member about said first axis to produce said yaw motion;
- a second housing member rotatably carried on said first housing member, second drive means connected between said first and second housing for rotating said second housing about said second axis to produce said pitch motion;
- a third housing member rotatably carried on said second housing member, third drive means connected between said third and second housings for rotating said third housing about said third axis to produce said roll motion;

said first, second, and third drive means each including a first gear means affixed to each of said respective housing members, a plurality of motor members disposed in spaced-apart, parallel relation within said housing members and second gear means operatively connected to the output shafts of said motor members for meshing with and rotating said first gear means; and

said motors being disposed to produce a required torque about each axis while enabling said housing members to be constructed of a reduced size so that said wrist joint assembly may be advantageously constructed to provide for good visibility around the joint.

11. The assembly as set forth in claim 10 wherein said yaw motion is between plus and minus 45°, said pitch motion is between plus and minus 90°, and said roll motion is continuous.

12. The assembly as set forth in claim 10 wherein said plurality of motor means includes three electrical motors, said second gear means includes a spur gear, and said first gear means includes a central spur gear meshing with each of said spur gears.

13. A wrist joint assembly for use with a mechanical manipulator arm for positioning an end-effector carried by said wrist joint adjacent the terminal end of said manipulator arm, wherein said wrist joint assembly is pivotable about a first axis to produce a yaw motion, a second axis to produce a pitch motion, and a third axis to produce a roll motion, said wrist joint assembly comprising:

a disk segment having an outwardly extending arm fixed to the terminal end of said manipulator arm;

a spherical housing member rotatably carried on said disk segment about said first axis, a motor means carried by said disk segment, first gear means rotatably driven by said motor means, second gear means fixed to said spherical housing and meshing with second gear means for rotating said spherical housing about said disk segment to produce said yaw motion;

a pair of spaced arm members pivotably carried on opposing sides of said spherical housing;

a pitch housing member affixed between said spaced arm members, motor means carried within said pitch housing, first gear means rotatably driven by said motor means, second gear means fixedly carried by said spherical housing and meshing with said first gear means so that rotation of said first gear means causes said pitch housing to rotate about said spherical housing to produce said pitch motion;

said pitch housing member having a cylindrical sleeve portion extending therefrom;

a roll housing member rotatably carried on said sleeve portion, motor means carried within said sleeve portion, first gear means rotatably driven by said motor means, second gear means affixed to said roll housing and meshing with said first gear means so as to cause said roll housing to rotate and produce said roll motion; and

a slip-ring member having a spindle portion affixed within said pitch housing, an outer casing of said slip-ring rotatably carried on said spindle in electrical contact therewith, said outer casing being connected to said roll housing so as to rotate therewith, conductor means connected between said end-effector and said outer casing to transmit electrical power and signals to said end-effector carried on said roll housing during continuous roll motion.

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