

Handbook
of
Theory And Manufacturing Procedure
For
AC Spark Plug Gyros

**AC SPARK PLUG DIVISION
GENERAL MOTORS CORPORATION
MILWAUKEE PLANT**

0007

Gyro Familiarization Manual

Handbook
of
Theory And Manufacturing Procedures
For
AC Spark Plug Gyros

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of
General Motors Corporation

This manual has been prepared by the Gyro Project Department of the Field Service Division of AC Spark Plug in cooperation with the Gyro Engineering Department and Gyro Production Department. The manual presents general gyroscopic theory and manufacturing concepts of AC Spark Plug gyros for use by all departments within AC Spark Plug associated with the need for gyro familiarization.

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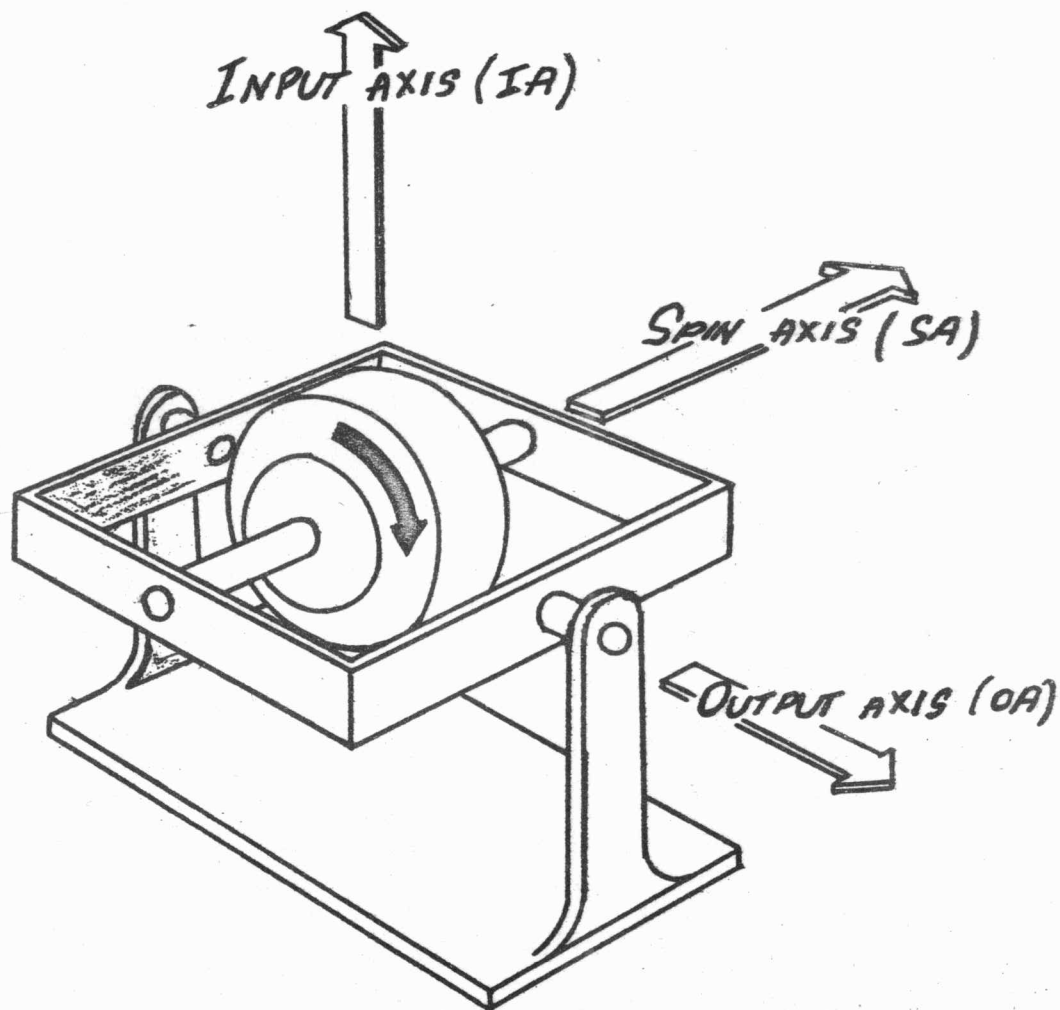
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I. GYROSCOPIC THEORY:

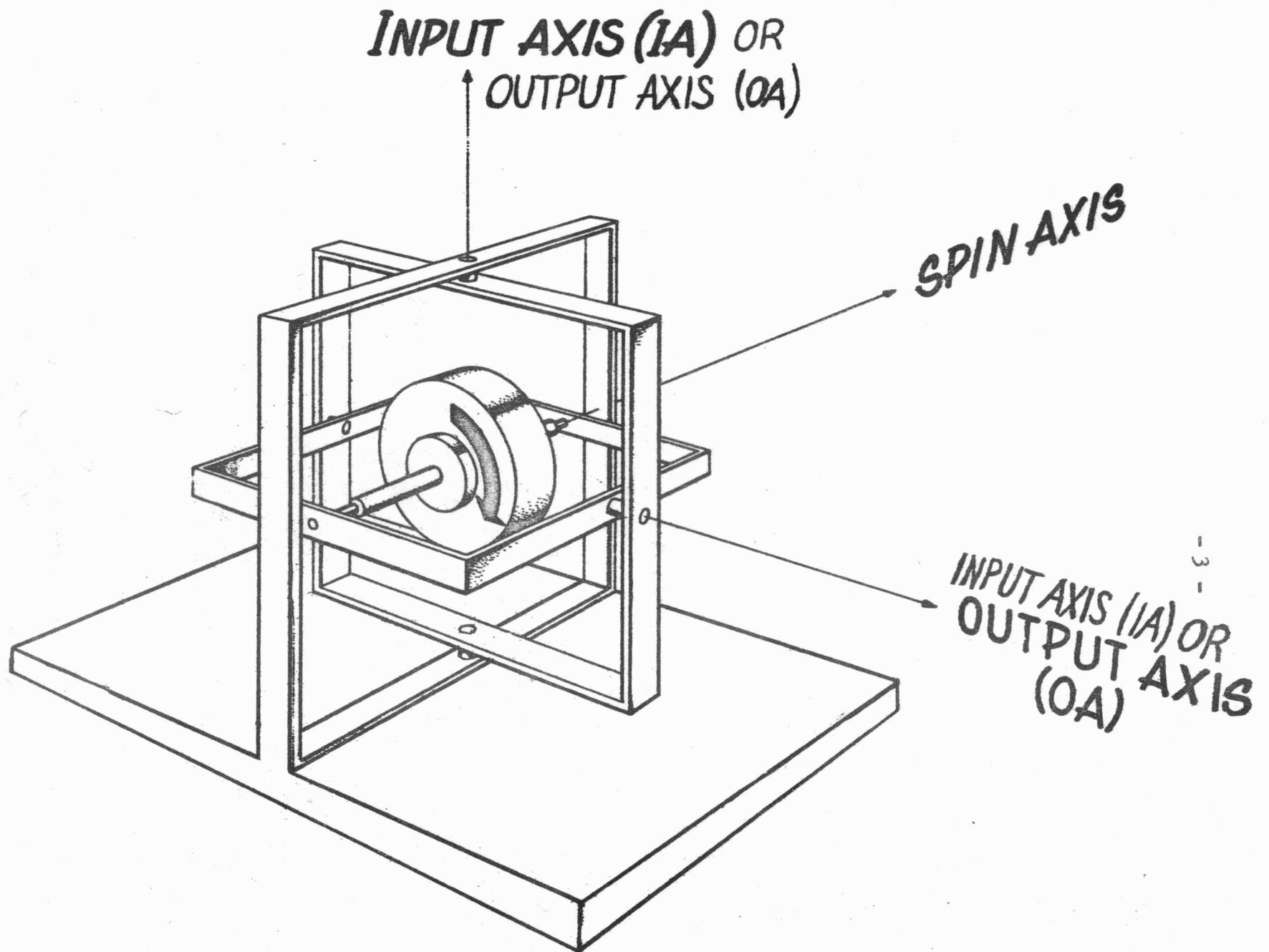
A. Definition:

A gyroscope may be defined as a rotating mass, in the form of a wheel, which is free to rotate about an axis mounted in a gimbal. A gimbal, in turn, is a mechanical frame containing two mutually perpendicular axes, one of which is the axis the gyro wheel rotates about. The other axis is used to permit the gimbal to rotate, (Figure 1-a). A gyro is classified by the number of degrees of freedom it has. A gyro mounted in one gimbal is said to have one degree of freedom. (This is true only if the gyro wheel is not rotating about an axis parallel with the gimbal axis.) A gyro mounted in two gimbals is then said to have two degrees of freedom. Two degrees of freedom is a limit even if a gyro were mounted in three gimbals. This is true since in this case the gyro would necessarily have to rotate about an axis which is parallel to one of the gimbal axis. Figures 1-a and 1-b show a single degree of freedom and a two degree of freedom gyro. Since all of the gyros presently manufactured by AC Spark Plug are single degree of freedom gyros, discussion will be limited to gyros of this type.

Gyroscopic action may be defined as the ability of the gyro element, generally known as the gyro wheel, to transmit an outside torque which is applied to an axis normal to both the spin axis (SA), of the gyro element and the plane in which the gimbal lies, to another axis which is also normal to the spin axis (SA) but



SINGLE DEGREE OF FREEDOM GYRO
Fig. 1 (a)



TWO DEGREES OF FREEDOM GYRO

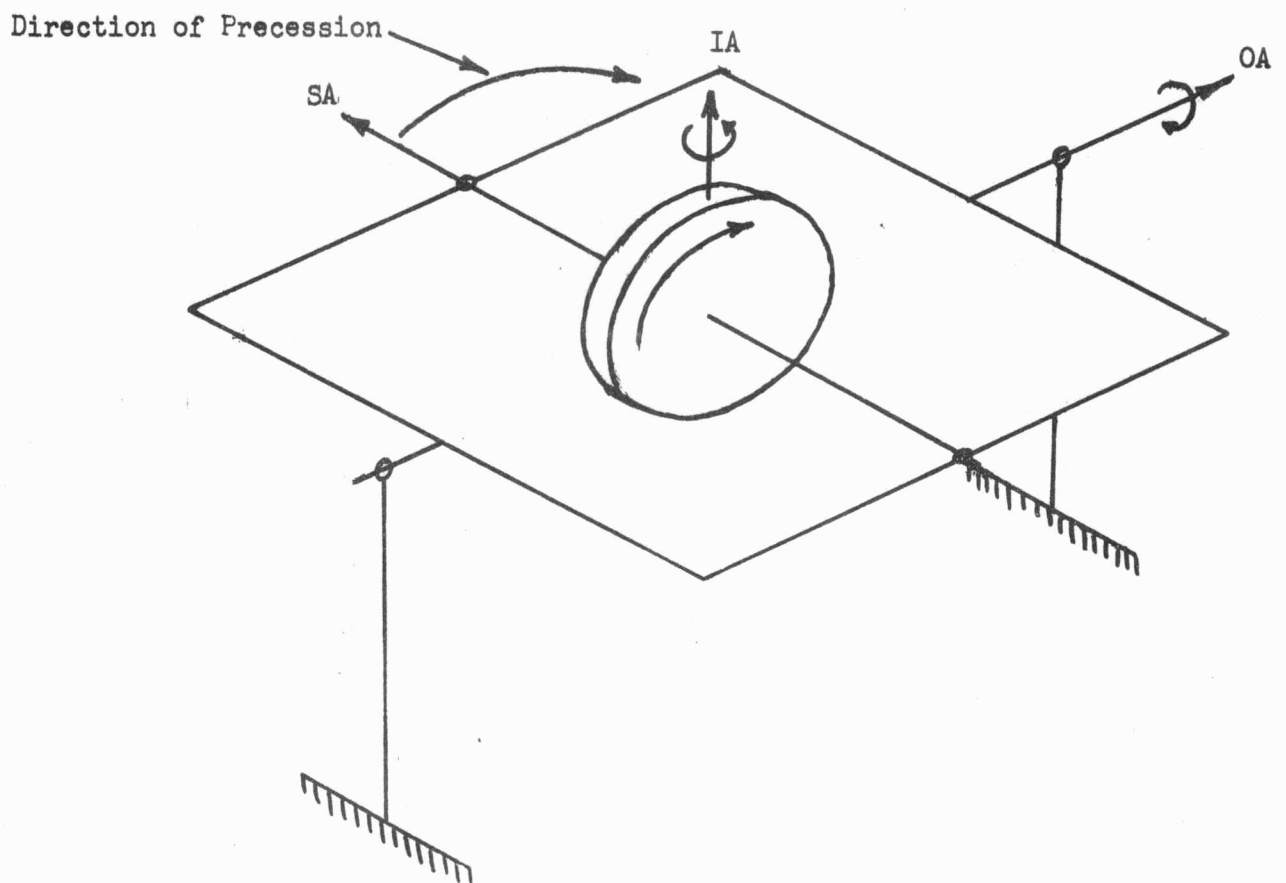
Fig. 1 (b)

which lies in the same plane as the gimbal. The axis about which the outside torque is applied is known as the input axis (IA), and the axis to which the torque is transmitted is known as the output axis (OA), Figure 2.

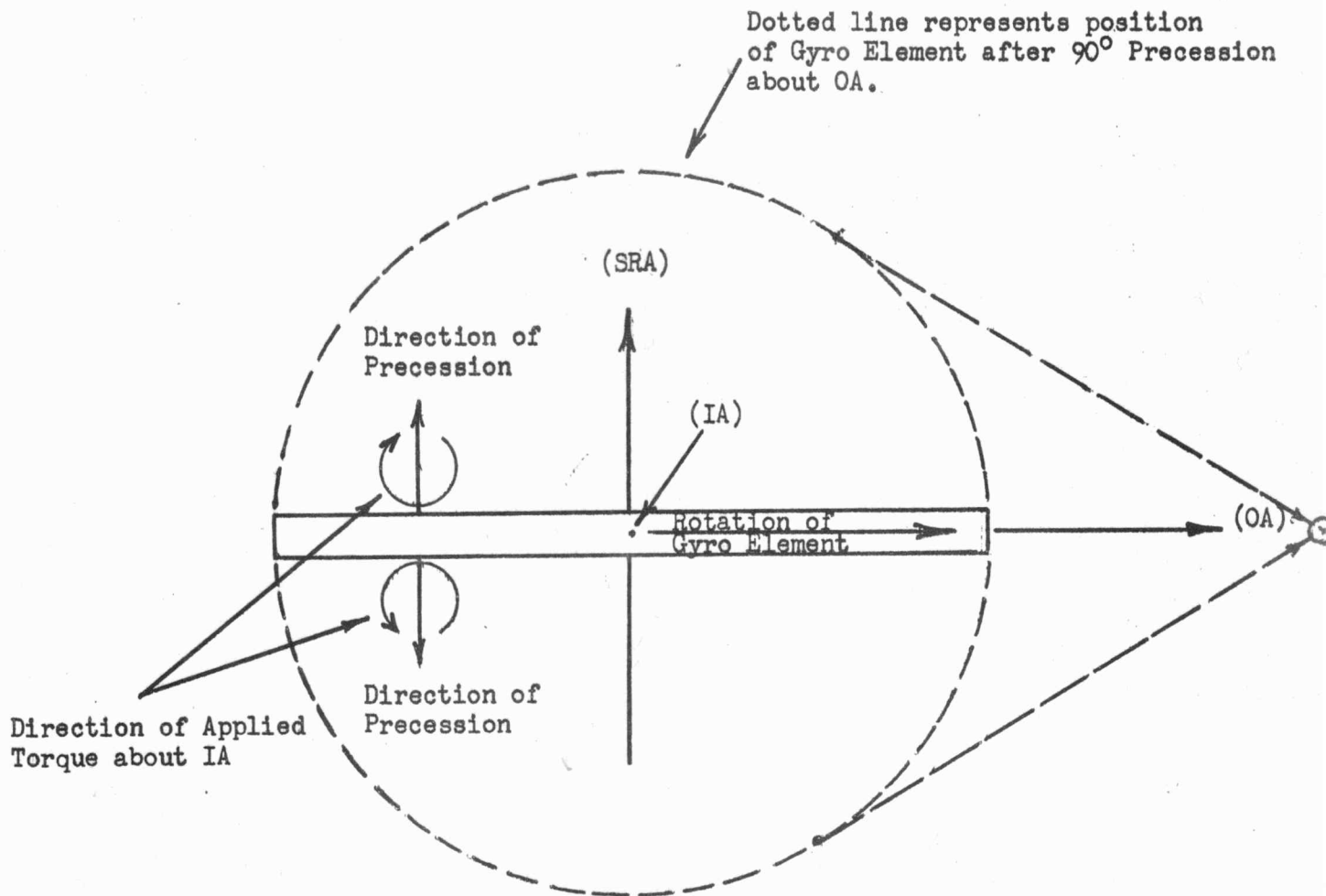
These two axes are 90° apart and each is 90° from the SA. The reason for the torque transmission lies within the ability of the gyro element to precess since it has one degree of freedom through the gimbal. The term precess refers to the property of the gyro to rotate about an axis, the OA, other than the one it is being forced to rotate around, the IA. Precession can also be explained by use of Newton's first law of motion concerning inertia of moving or stationary bodies.

Considering a single point on the circumference of the gyro element, at any instant in time it will have a tangential velocity vector pointing to a point in space which it will attempt to follow due to centrifugal force, Figure 3. Observing the gyro element from a point in space above it, IA appearing as a point, it is noted that applying a torque about the input axis in either direction will cause the gyro element to precess in such a manner as to cause the velocity vector to attempt to always point toward the same point in space, assuming the same instant in time is considered.

A much simpler method of determining direction of precession is the right hand rule. First considering the direction of gyro element rotation, when the fingers of the right hand are curved in the direction of rotation, the thumb will point toward the plus end of the S.A



GYRO AXIS IDENTIFICATION



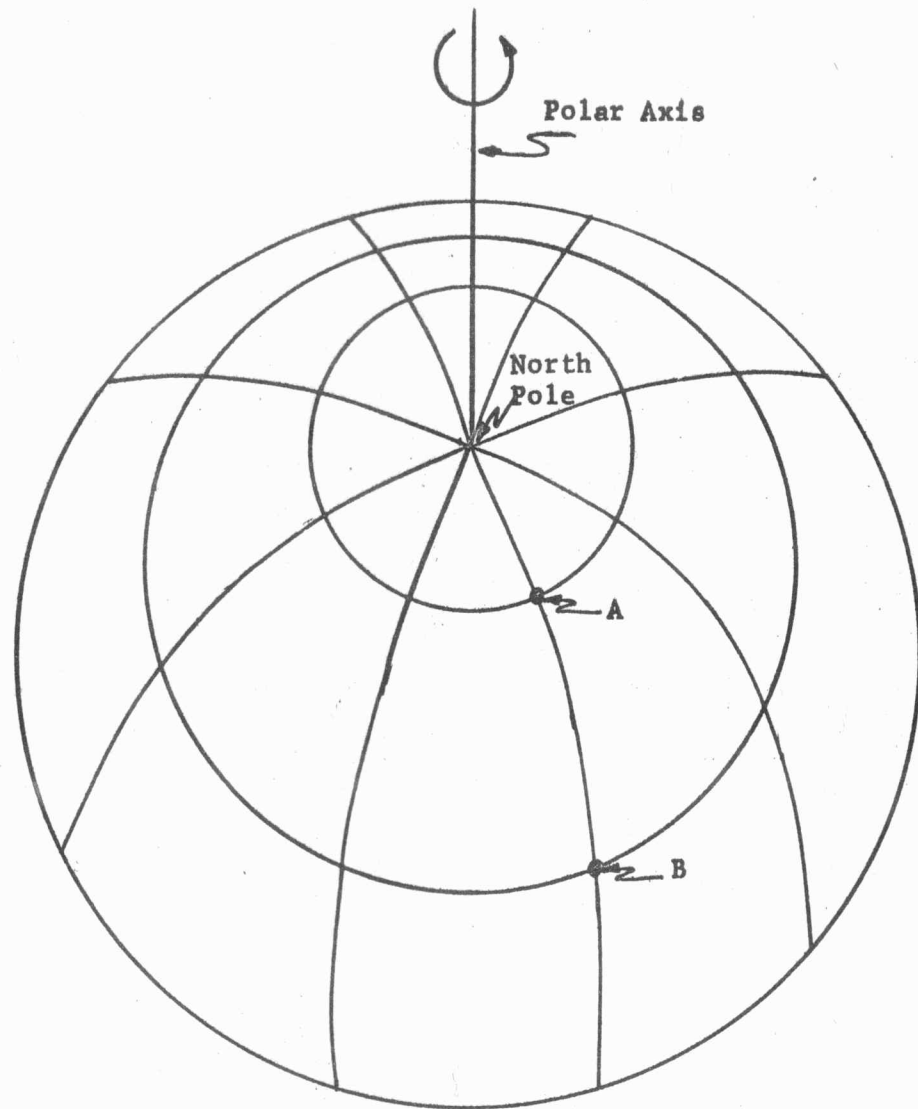
PRECESSIONAL TORQUE

Fig. 3

Similarly, when the fingers of the right hand are curved in the direction of applied torque about IA, the thumb will point toward the plus end of the IA.

When a torque is applied about the IA, the plus end of the SA will attempt to move toward the plus end of the IA. It must be noted here that when using this rule to determine direction of precession, it is necessary to remember that the direction is always from the plus end of the SA to the plus end of the IA. The torque which results about the OA due to precession is known as gyroscopic torque. It is necessary at this point to acquaint the reader with a fourth axis which is an integral part of the gyro. This axis is called the spin reference axis (SRA). The SRA is a reference from which the degree of precession is established. The SA and the SRA are coincidental when the gyro is nulled or has experienced no precession. The SRA is, as has been stated previously, a reference and thus it always remains 90° from the IA when precession occurs.

The entire phenomena of gyroscopic action is caused by a force known as Coriolis Force. A coriolis force is developed whenever an object is rotating about two axes simultaneously. As an example, let us assume there is a body located at a point A on the surface of the earth as shown in Figure 4. In a 24 hour period this body must move a distance equal to the circumference of the earth at the particular latitude of point A around an axis through the poles. It therefore must have a component of velocity directed toward the East with respect to an observer in space.



DRAWING OF EARTH SHOWING CORIOLIS FORCES

Fig. 4

If the body were located nearer the equator, such as at point B, it would have a greater eastward velocity since the circumference of the earth is greater near the equator. Thus, if the body is caused to move toward the equator from point A along a longitudinal path to point B, it will necessarily have to be constantly accelerated in order to attain the velocity of the surrounding earth.

Since an acceleration implies that a force is being applied, we may assume there is a force acting on the body due to the surrounding earth in the direction of earth's rotation. By Newton's third law of motion, which states that for every action there must be an equal and opposite reaction, there must also be a force acting upon the earth due to the body which tends to oppose earth's rotation. The force which acts upon the earth is called the coriolis force.

If the body is moved away from the equator instead of toward it, the coriolis force is reversed. In this case the body would have a greater velocity than the surrounding earth and would cause a force to act upon the earth in the direction of earth's rotation. A complete description of the coriolis force can be given as follows: A body moving toward either of the poles from the equator will cause a force to act upon the earth which is in the same direction of earth's rotation and a body moving toward the equator will cause a force to act upon the earth which opposes earth's rotation.

The magnitude of the coriolis force depends upon several things. First, it depends upon the mass of the body that was moved, and secondly it depends upon how rapidly the velocity of the body has changed in the

direction of earth's rotation. This change in velocity, in turn, is dependent upon two things. First, it depends upon the velocity of any point on the earth's surface which can be determined by knowing the angular velocity (w) of the earth, and secondly it depends upon the change in the distance of the body from the polar axis. Thus, the coriolis force may be represented by the formula:

$$F = K m w \Delta r$$

Where:

K = constant

m = mass of the body

w = angular velocity of the earth

Δr = change in radius to the polar axis

Since K , m and w are all constants, the magnitude of the coriolis force depends only upon the change in r (Δr). An analogy can be made between the body moving on the earth's surface and the spinning gyro element. The formula above would hold true for a gyro where:

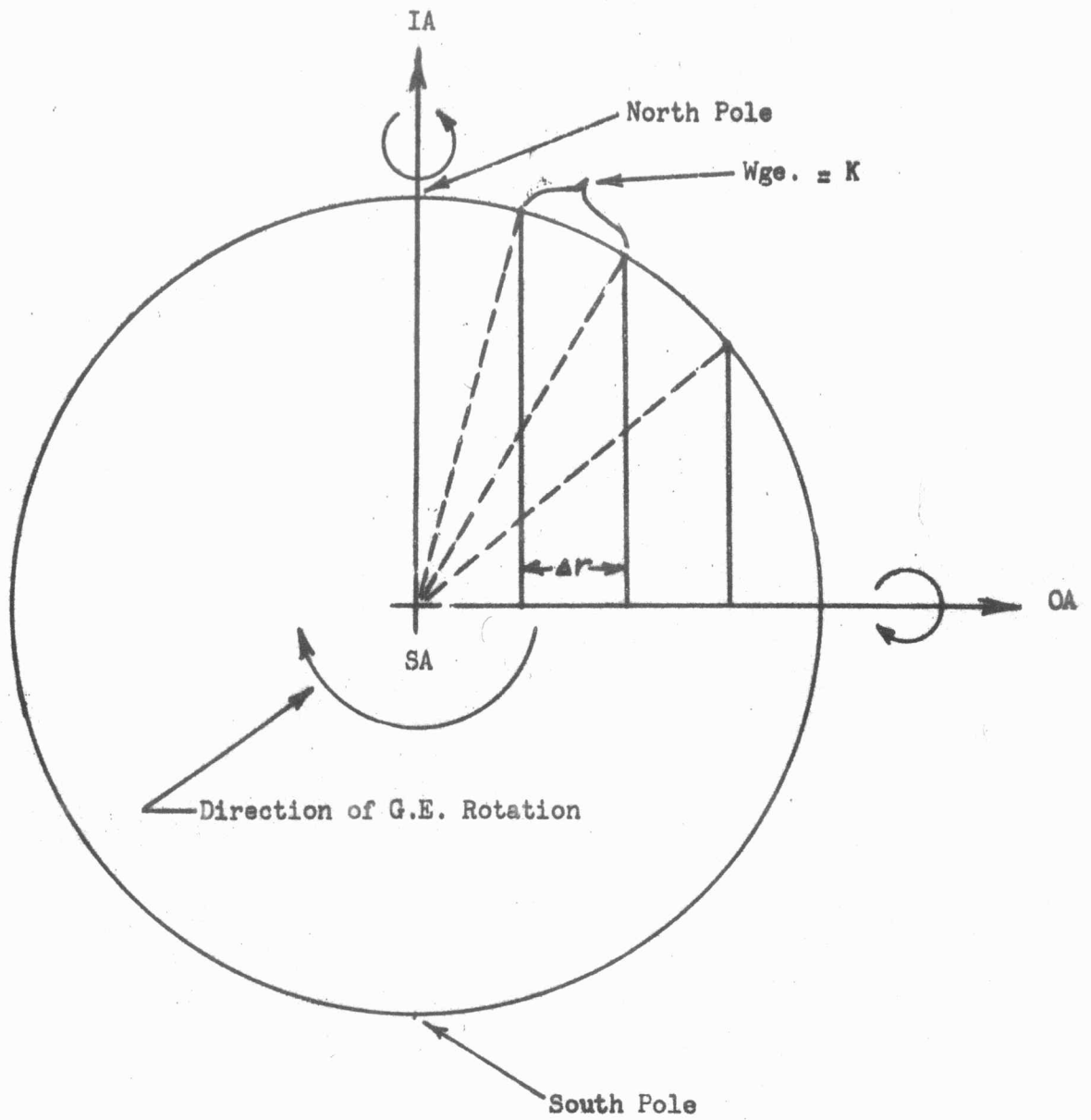
K = constant

m = mass of a particle on the circumference of the spinning wheel

w = angular velocity of a torque applied about the gyro IA

Δr = change in radius of the particle on the circumference of the spinning wheel to the IA

Recognizing the fact that all particles on the gyro element behave in the same manner, all particles of the gyro element are moving at a constant angular velocity about the SA just as the body on the earth's surface moved from the North Pole toward the equator. If an external torque is applied about the IA, the gyro element will attempt to rotate about the IA just as the earth rotates about its



Coriolis Force

Fig. 5

polar axis. The two rotations simultaneously will produce a coriolis force to act upon the gyro element causing it to precess and produce a torque about OA. The torque produced about OA can be expressed by the formula:

$$T_{OA} = W_{IA} \times H_{SA}$$

Where:

T_{OA} = gyroscopic torque or torque about OA

W_{IA} = angular velocity of the torque applied about IA

H_{SA} = angular momentum about SA of the gyro wheel

It should be noted that any variation of H_{SA} will critically effect the torque produced about OA. For the output torque about OA to vary proportionally with the angular velocity of the torque applied about IA in such a way as to be utilized effectively, the angular momentum of the wheel about SA (H_{SA}), must remain constant. This is accomplished in most gyros by use of a synchronous motor to drive the gyro element at a constant velocity. Since synchronous motors are dependent upon frequency of the input voltage to the motor, a frequency regulator is used to critically control the voltage frequency and thus control motor speed at a constant value. The synchronous motor is a physical and integral part of the gyro wheel, thus control of motor speed automatically controls gyro wheel speed.

It must also be mentioned here that if the body on the earth's surface is moved at a constant angular velocity from point A to point B, the radius to the polar axis changes most rapidly at the pole. Thus, the coriolis force is a maximum at the pole and decreases to zero at the equator. The same holds true for the gyro element. As the SA of the

gyro element precesses toward the IA, the coriolis force diminished constantly since the particles of the gyro element tend to move about the IA rather than away from it. As 90° of precession is approached, the coriolis force goes to zero.

Single degree of freedom gyros can be divided into three types, each of which responds to a gyroscopic action about the OA in a different manner. The response of a gyro will depend upon what type restraint is applied to the gimbal. If the resistance to motion of the gimbal is due only to the inertia of the gimbal and gyro element and to the bearing friction of the gimbal, the gyro is known as an integrating gyro. This type gyro has previously been illustrated in Figure 2.

The integrating gyro is seldom used and its name has become confused with that of the rate-integrating gyro. The term "integrating" is often used when discussing what is actually a rate-integrating type.

A rate-integrating gyro is one which has a viscous restraint applied to it in addition to its inertial and frictional restraints. A viscous restraint produces a torque which is proportional to the angular velocity of the gyro gimbal about the OA and directed so as to oppose the motion of the gimbal. Thus, the gyro gimbal will be accelerated until an angular velocity is reached at which the viscous torque is equal and opposite to the gyroscopic torque. Since the angular velocity of the gimbal is proportional to the gyroscopic torque, the change in position of the gimbal during any time interval will be proportional to the integral of the input angular velocity. Hence, the gyro is called a rate-integrating gyro.

A viscous restraint will be provided if a gyro gimbal is placed in a fluid as shown in Figure 6. In the figure, the gyro gimbal completely encloses the gyro element so that the fluid will have no torquing effect about the gyro element SA. As the gimbal begins to move, the layers of fluid near the gimbal tend to move while the layers further away from the gimbal tend to remain stationary. This movement between layers of the fluid produces a stress in the fluid which opposes gimbal motion. Since a linear relationship between the angular velocity of the gimbal and the viscous stress of the fluid is sometimes desirable, a special fluid which has this linearity is often used.

The property of a fluid to set up stresses and to produce viscous torquing is called damping. Following is a formula for finding angular velocity at which a gyro rotates about the OA when damping is involved.

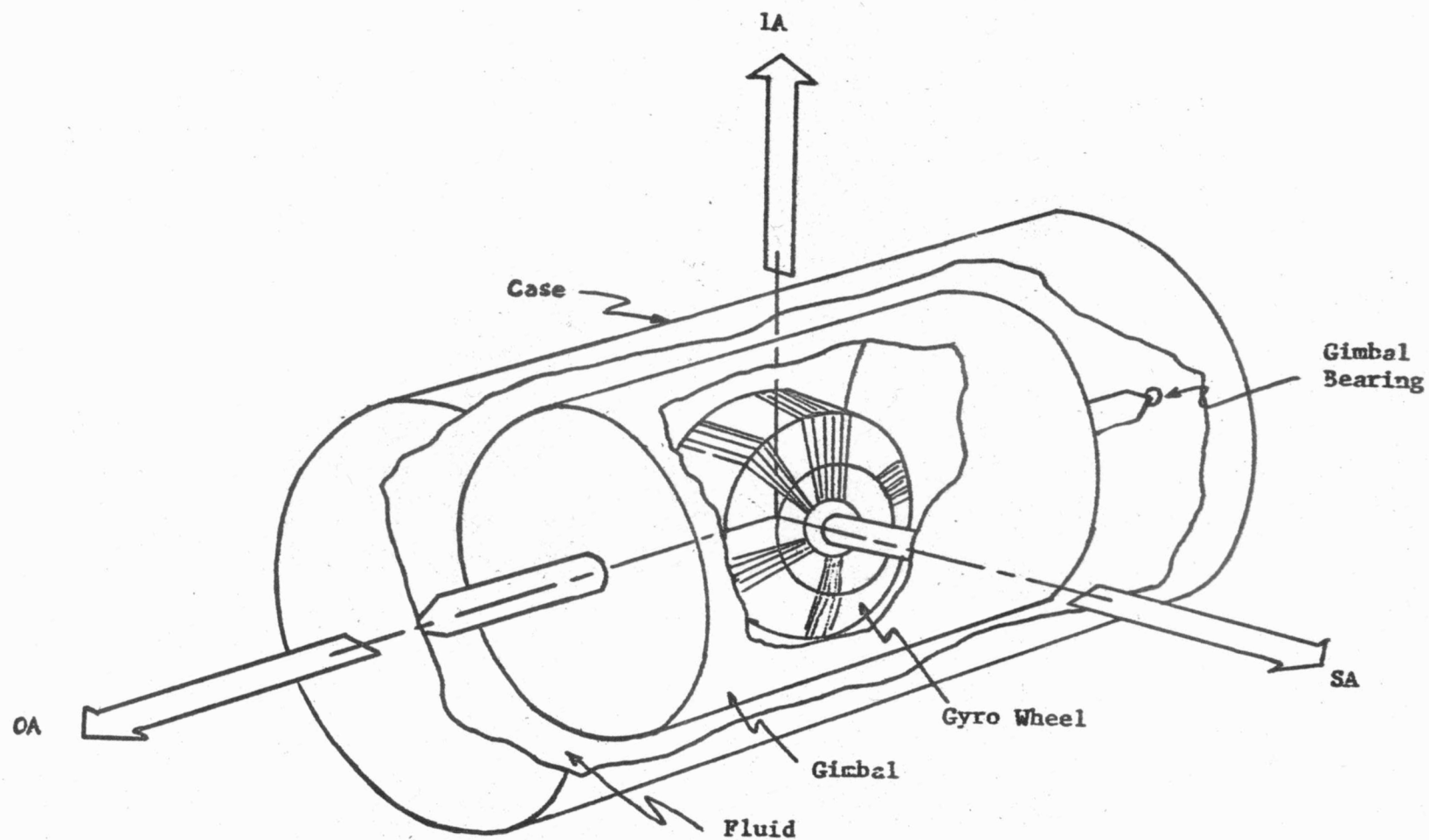
$$T_{OA} = C_D \times W_{OA}$$

Where: T_{OA} = torque about the OA

C_D = coefficient of damping

W_{OA} = angular velocity about the OA

A gyro which is not only restrained by inertial, frictional and viscous restraints, but is also elastically restrained by use of such things as springs or torsion bars is called a rate gyro. An elastic restraint is one which produces a restraining torque proportional to the distance the gimbal has moved from its null, or centered position. Whenever a rotating gyro gimbal reaches a point where the elastic res-



RATE INTEGRATING GYRO

Fig. 6

straint is equal to the gyroscopic torque, the gimbal will stop rotating and provide an angular position indication which is proportional to the input angular velocity. A rate gyro could be constructed from the rate-integrating gyro shown in Figure 6 by attaching a spring to the gimbal to produce the desired elastic restraint.

Of the three types of gyros discussed thus far, AC Spark Plug presently manufactures both the rate-integrating and the rate gyro. These gyros are used for two different applications, these being stabilization and accelerometer gyros. Each of these will be examined and explained in more detail later.

In addition to the torques thus far mentioned that effect gyro operation, another torque referred to as Friction Torque markedly effects gyro operation. Since in most applications frictional torques greatly degrade gyro operation, great pains are taken to reduce them as much as possible.

One type of friction, known as Coulomb Friction, is caused by and is directly proportional to the pressure between gimbal pivots and the gimbal pivot bearings. Since much of this friction is caused by the weight of the gimbal and the gyro element, it can be reduced to nearly zero by using a viscous damping fluid which has the same average density as the gimbal assembly. In this manner the same viscous substance utilized for restraining purposes as previously mentioned may be used for flotation purposes to buoy up the gyro gimbal, (or float as it is called when it completely surrounds the gyro element), thus reducing bearing friction to a very small amount. Gyros using a viscous damping substance for flotation purposes are referred to as floated gyros. All of the gyros

presently manufactured by AC Spark Plug are floated gyros.

Another method presently employed on some gyros to aid flotation in decreasing friction between pivots and pivot bearings is magnetic suspension. Magnetic suspension is an electrical aid utilizing an eight pole microsyn which is wired such that it builds up a magnetic field about the pivot end, thus holding the pivot in the bearing center. Microsyn operation will be discussed in greater detail later.

Gyroscopes are often misunderstood due to the incorrect impression that a gyro tends to remain rigid in space. Actually, if a gyro is intended to remain rigid in space it must be gimballed about three axes to allow unrestricted movement such that no outside torques are able to act upon the gyro element. A gyro may be moved about any axis just as easily as a stationary block with the same inertia if the input torque is applied about the proper axis. The property of a gyro which differs from that of a stationary mass is that a gyro will rotate about an axis other than the one about which the outside torque is being applied.

B. Stabilization Gyros:

Since man first began to increase his movements about the face of the earth to the present age of space exploration, a need for orientation with his surroundings has existed. There is available today an extremely sensitive and accurate means with which to navigate on water, under the water or in space. Navigation of extreme accuracy has been made possible through the

use of gyros in a system known as inertial guidance. One of the important functions of an inertial guidance system is to accurately control a stabilized platform, which may be referred to as a controlled member, to insure adherence to a fine line of reference from which the desired navigation might be performed. The duty of maintaining a controlled member in the desired orientation falls to the unit known as the stabilization gyro.

The stabilization gyros manufactured by AC Spark Plug are single degree of freedom, rate-integrating, floated gyros. A simple illustration of the type of gyro just mentioned is given in Figure 6. Beginning with the innermost parts, a simple gyro configuration will be given along with the functions of each component part.

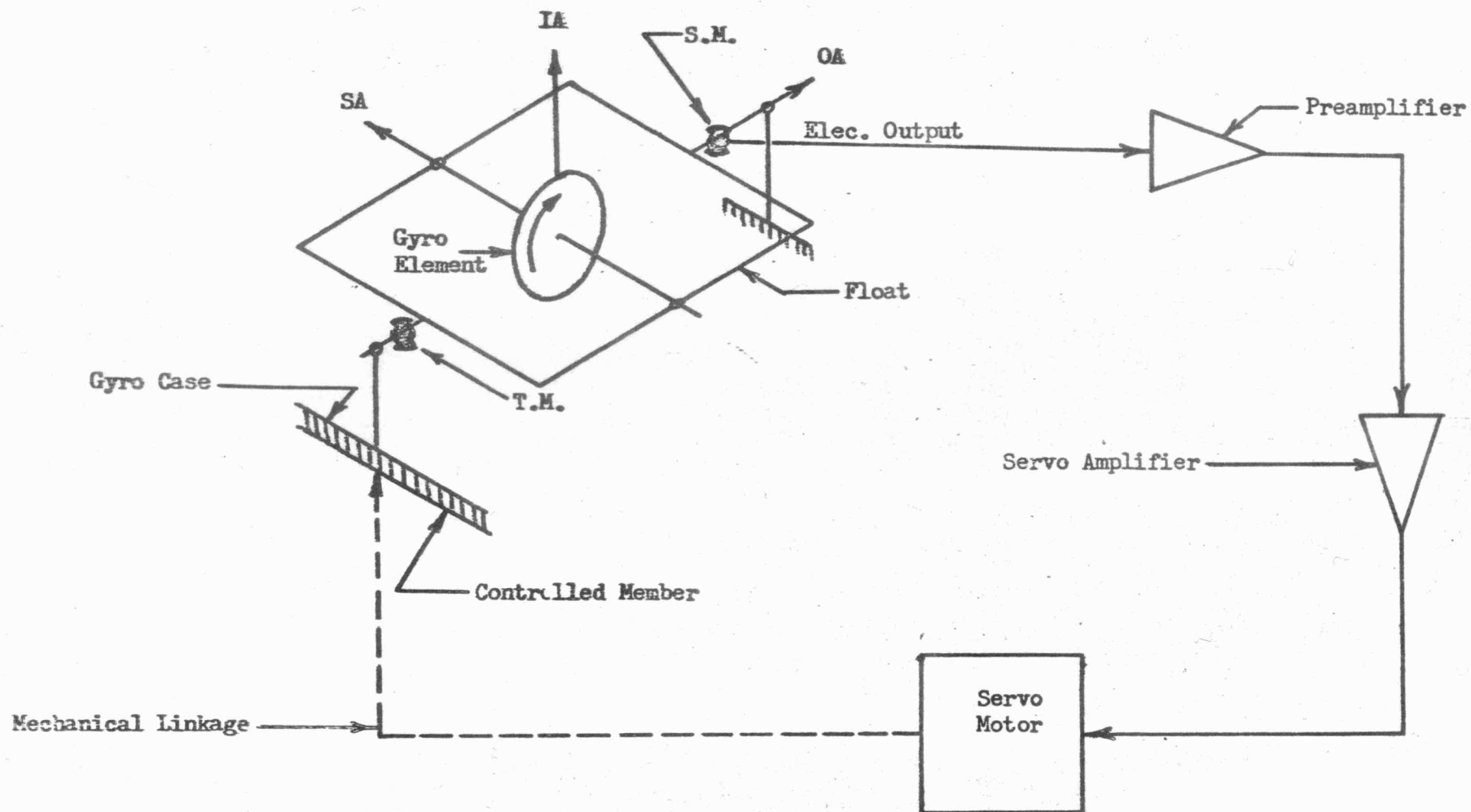
The primary action of a gyro is that of the gyro element. It is spun about the SA at a given constant speed. The end points of the SA are physically attached to the float such that any precession of the gyro element automatically causes an angular movement of the float. The float ends are pivoted within the gyro case in jewel bearings and the area between float and case entirely filled with a viscous damping fluid. The gyro is so constructed that the pivot axis of the float is coincidental with and assumes the function of the gyro OA. The gyro case is attached to the controlled member in such a manner that any movement or angular acceleration of the controlled member produces an input torque about the gyro IA.

Since an angular acceleration about IA produces a proportional gyroscopic torque about OA, the attitude of the controlled member can be maintained by utilizing the gyroscopic torque in the form of an electrical signal. This is accomplished by use of a torque generator (T.G.) and a signal generator (S.G.). The T.G. is physically attached to one end of the gyro case concentric to the OA and the S.G. is physically attached to the other end of the gyro case concentric to the gyro OA. The function of the T.G. is to transform an electrical signal to a mechanical movement and conversely the function of the S.G. is to transform a mechanical movement into an electrical signal. Both the T.G. and the S.G. consist of two parts, a stator winding and a metal rotor which moves angularly within the stator. The rotor is physically attached to the pivot end of the float, hence any movement of the float causes a movement of the rotor within the stator. A more detailed discussion of both the T.G. and the S.G. will be gone into later.

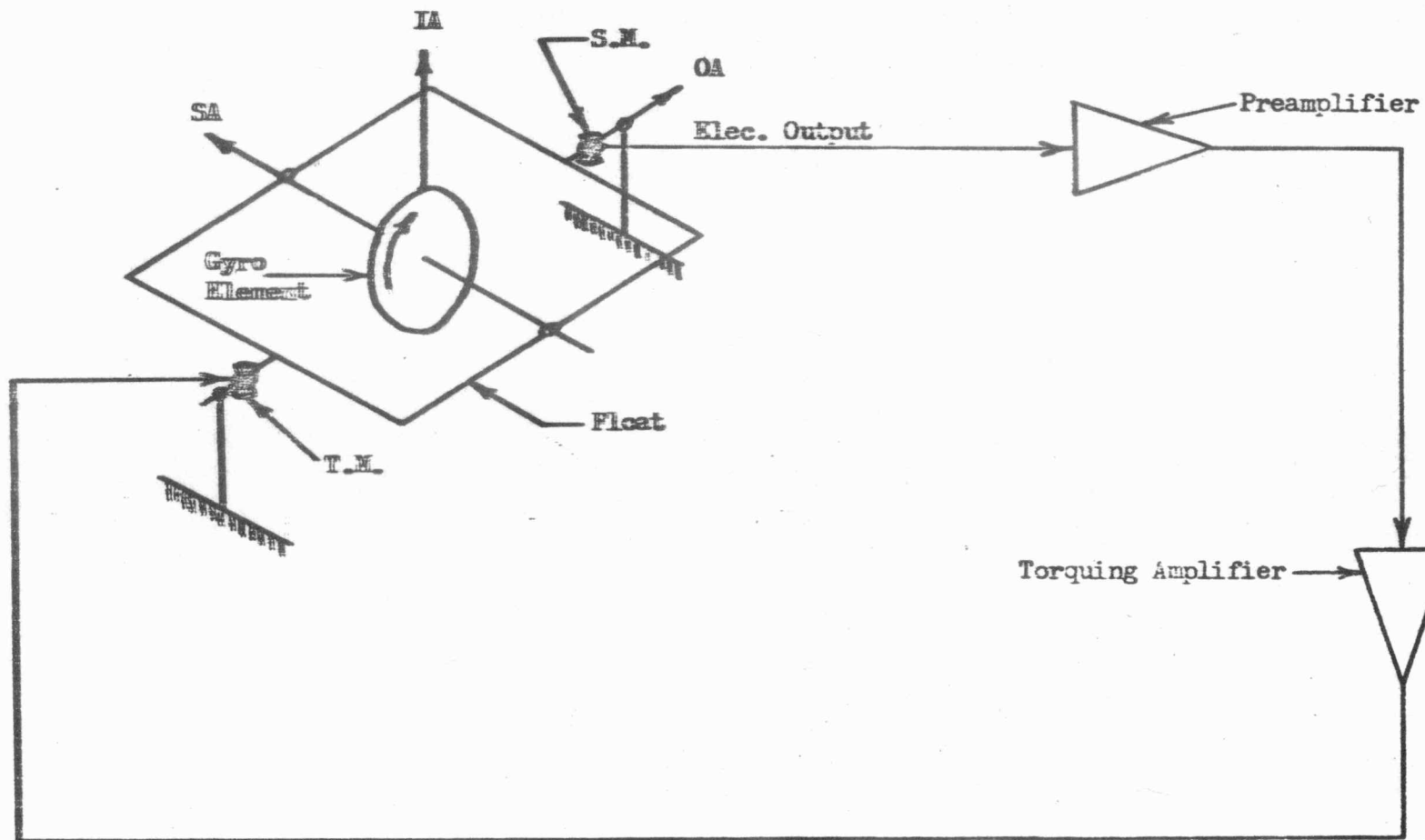
Both the T.G. and the S.G. are aligned on the OA such that they reach a condition of no output, or null, simultaneously. The float is equipped with mechanical stops which limit float rotation to a very small arc and prevent the T.G. and S.G. from reaching electrical saturation. An excessive amount of float freedom, or gyro element precession, is not necessary since the response time for error correction is such that the float will normally never rotate to a position where the mechanical stops are engaged before the error is driven out.

Since the gyro case is physically attached to the controlled member and since the error or controlled movement takes place between the gyro case and the float, any movement of the controlled member about the gyro IA will be felt by the gyro element causing it to precess. As it precesses, the float and the S.G. with it, rotate causing an electrical output from the S.G. This output is used to operate a servo motor which in turn drives out the controlled member error angle. As the controlled member is driven back toward a null, it produces a reverse torque about the IA from the original movement. This causes the gyro element to precess in the opposite direction, thus returning the S.G. toward a null position. When a condition of no S.G. output occurs, the servo motor stops driving the controlled member and a static condition exists until another controlled member movement takes place.

A simple control diagram using a stabilization gyro is shown in Figure 7. If a completely stabilized platform is desired along three mutually perpendicular axes, it would be necessary to incorporate three stabilization gyros whose input axes were mutually perpendicular to facilitate sensing angular accelerations about three platform axes. It would also be necessary to employ three gimbals, or controlled member, whose axes were also mutually perpendicular to allow free movement of the stabilized platform. In addition to using the S.G. output in a servo loop to drive the servo motor, the same output is employed to null the gyro as shown in Figure 8. In this configuration the electrical signal from the



Simplified Control Diagram



Simplified Nulling Diagram
Fig. 8

S.G. is amplified and returned to the T.G. which torques out any error in S.G. position with respect to null, thus aligning the float to its center or null position. Again, as the error is felt by the S.G., it sends a signal to the T.G. to correct this error and as the T.G. drives the float in an angular movement the S.G. returns to zero output, thus stopping the T.G. action and again a null condition exists.

No attempt has been made here to explain all applications and operations of a stabilization gyro, but merely to familiarize the reader with the basic functions from which he may expand. Actually, under varying applications, many variations may be used which are peculiar to a particular system requirement or design. It must be remembered that this basic gyro configuration is characteristic of all AC Spark Plug manufactured gyros.

C. Accelerometer Gyros:

The operation of an accelerometer gyro is basically the same as that of a stabilization gyro in that it is a rate-integrating, single degree of freedom, floated gyro. The major design difference is in the gyro wheel. Gyros are employed in a guidance system to perform two functions. These functions are to sense any deviation of the stabilized platform from the desired orientation, which has been discussed, and to sense any acceleration of the platform while in or out of the desired orientation. The latter duty falls to the accelerometer gyro. The accelerometer gyros must sense acceleration along any of the three system axes or a combination of accelerations between any of the axes.

Along with the difference in gyro wheel design from that of the stabilization gyro, the accelerometer gyro reacts differently than the stabilization gyro in that it will sense an acceleration along its IA rather than react to an angular velocity about its IA.

The second, or the reaction, is a direct result of the first, or gyro wheel design. An accelerometer gyro has a specified amount of precision unbalance displaced along the plus SA and any acceleration along the IA will cause the gyro element to act as a pendulum, thus producing precession and an output torque about OA. The precision unbalance of the gyro along the plus SA represents the action of the gyro known as pendulosity. The degree of pendulosity incorporated into a gyro determines the degree of gyroscopic torque for a given acceleration. The gyroscopic torque produced causes an angular movement of both the float and S.G. The S.G. output is utilized to drive a servo motor which is mechanically linked to the accelerometer, driving it about its IA. Thus, the accelerometer gyro has become an ACCELEROMETER. It must be remembered that the accelerometer gyro in itself is not a complete ACCELEROMETER. The related feedback servo system is necessary for the gyro to attain this end.

To accomplish this, it is necessary to mount the gyro in a housing which is pivoted on an axis coincident with the gyro IA. The direction of the accelerometer rotation about IA produces a torque about the gyro IA and a gyro element precession in opposition to pendulosity, thus attempting to maintain a gyro null. The entire process will produce a constant angular velocity of the accelerometer for a given angle-

ration along the IA. As the accelerometer experiences an increase in acceleration along IA, the rotational angular velocity about IA will increase proportionally. The gyro function of integration stems from its ability to distinguish a rate of change of velocity, (acceleration), along the gyro IA and transform it into a proportional angular velocity about IA. This ability forms the basis for the term Pendulous Integrating Gyro.

II. GYRO PARTS AND ASSEMBLY:

Each of the gyros being considered will be treated individually and in turn. Major part names are listed in tabular form and will be identified while assembly sequence and procedure is being discussed.

1.0×10^7 RATE INTEGRATING GYRO (MOD. II)

<u>Part Name:</u>	<u>Number Required:</u>
Trunion	2 (1 each end)
Main Housing	1
End Housings	2
Jewel Bearings	2
Float Pivots	2
Baffles (metal)	2
Baffles (plastic)	4
Flex Leads	4
Bellows	8 (4 each end)
Balance Pins	As Required
Float Housing	1

Float End Plates	2
Gyro Wheel	1
Gyro Shaft (SA)	1
Wheel Bearings	2
Motor Stator	1
Hysteresis Rings	- -
Heating Element	3 (2 End Housing, 1 Main Housing)
Sensing Element	1
Microsyn Rotors	2
Microsyn Stators	2
Balance Forks	2 (On front end of Main Housing)
Venier Nuts	4 (On front of float)
Stop Pins	2 (On front of float)
Seal Ball	2 (1 each end Main Housing)
Sealing Ball Screw	2
Balance Studs	4

The following is an outline form of gyro assembly which closely follows actual manufacturing procedures:

I. Visual Inspection of all Parts:

A. Deburr parts where necessary.

1. This is a particularly critical area in gyro production. Since extremely close tolerances are maintained, any foreign material within the moving parts will seriously degrade gyro performance. Particles of foreign material too small to be detected by the unaided eye will cause adverse consequences. Thus, all cleaning, deburring and the major part of assembly must be done under powerful microscopes.

II. Wheel Package Assembly:

A. Mating Hysteresis Rings to Gyro Wheel:

1. The hysteresis rings are made of a material which possesses the magnetic qualities necessary to cause the gyro wheel, to which they are physically attached, to respond as the rotor of a motor. An interference fit exists between the rings and the shoulder inside the wheel face.

B. Bearing Selection:

1. The appropriate size bearings are selected to fit the gyro wheel. At the same time the properly sized bearing spacers are selected to insure proper preload conditions.

C. Motor Stator:

1. The motor stator consists of wire wound core which fits inside the gyro wheel and physically attached to the gyro shaft.

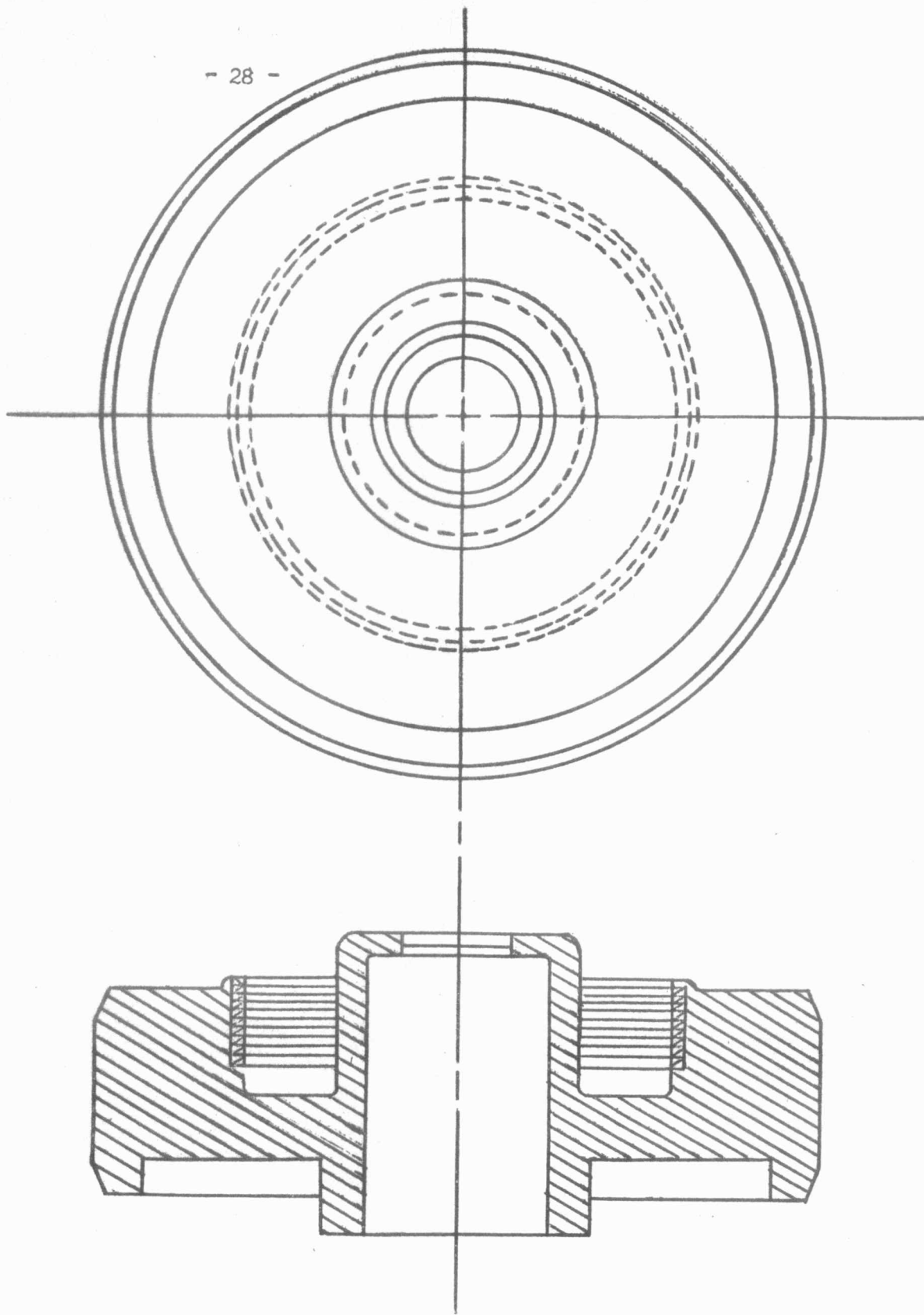
D. Gyro Shaft (SA)

1. The gyro wheel, bearings, bearing spacers and the motor stator are mounted on the gyro shaft to comprise the wheel package. Appropriate preloading is employed to insure proper bearing and spacer fit.

III. Float Assembly:

- A. One end of the gyro shaft is threaded and the other has a hexagonal head much like a simple bolt. The threaded end is inserted thru the minus SA side of the float and the wheel package is installed on the gyro shaft. The threaded end of the gyro shaft extends thru the float mount and a nut is threaded on and tightened to ensure proper fit of bearing spacers. This also accomplishes bearing preloading.

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1.0×10^7 Rate Integrating Gyro Wheel

- B. The next operation performed is to install the float end plates.

These are machined to give an interference fit and are drawn down with cap screws. Once the end plates are properly and firmly positioned, all float joints are sealed with cement. The float is then evacuated of all air by pressurizing with Helium and leak checking is done employing a Mass Spectrometer which is sensitive to Helium gas. After leak checking is completed, a quantity of Helium is left inside the float equal to a pressure slightly over atmospheric. The purpose of the Helium being left inside the float is to insure a minimum of oxidation and to reduce wind friction effects on the gyro wheel.

IV. Microsyn Rotor Mounting:

- A. The torque and signal microsyn rotors are fitted over the stud shafts on both ends of the float. They are aligned to insure coincidence of their symmetrical axes and firmly tightened down with the two holding screws provided for each rotor.

V. Float Pivot Mounting:

- A. Each of the float end plates has a protruding stub shaft which has a drilled hole to receive the pivot body with an interference fit. These drilled holes are on the float longitudinal axis and so situated to allow the installed pivot to assume the gyro OA. The pivots are pressed into place and checked for concentricity about the float longitudinal axis.

VI. Float Balancing:

A. Rotational Balancing:

1. A balancing tank fixture is employed for rotational balancing using two fluids of different density. One fluid density is such that it

will allow the float to sink and the other fluid tends to buoy the float up. A set of roller bearings fixed side by side on both ends of the tank are employed to either suspend the float by the pivots in the lighter fluid or to depress the float in the heavier fluid. (See Figure 9). In both cases the float is completely immersed in the fluid. The float is first balanced in the less dense fluid and then in the more dense fluid to insure proper balance. If the float is out of balance rotationally, it will tend to rotate about its longitudinal axis in the fluid. Coarse balancing is accomplished by adding balance pins into drilled holes in the ends of the float in the end plates. The holes are drilled in the end plates near the circumferential edge. Fine balancing is accomplished by adjustment of the vernier nuts.

B. Longitudinal Balancing:

1. Again a tank fixture is used but no bearing supports are used.

In this case the supports are in the form of wires leading from one end of a balance scale to the pivots of the float. (Figure 10) The fluid used is an approximate one-half to one-half solution of the two fluids used for rotational balancing. The object is to reach a fluid density which just begins to buoy the float so as to put the least moment possible on the balance arm and yet not entirely remove the float weight. The longitudinal unbalance will be evidenced by a difference in scale readings. As before, coarse balancing is accomplished by use of balance pins, being careful to split the total unbalance between the two pins and placing these 180° from each other around the end plate circumference so as not

Rotational Balancing Fixture

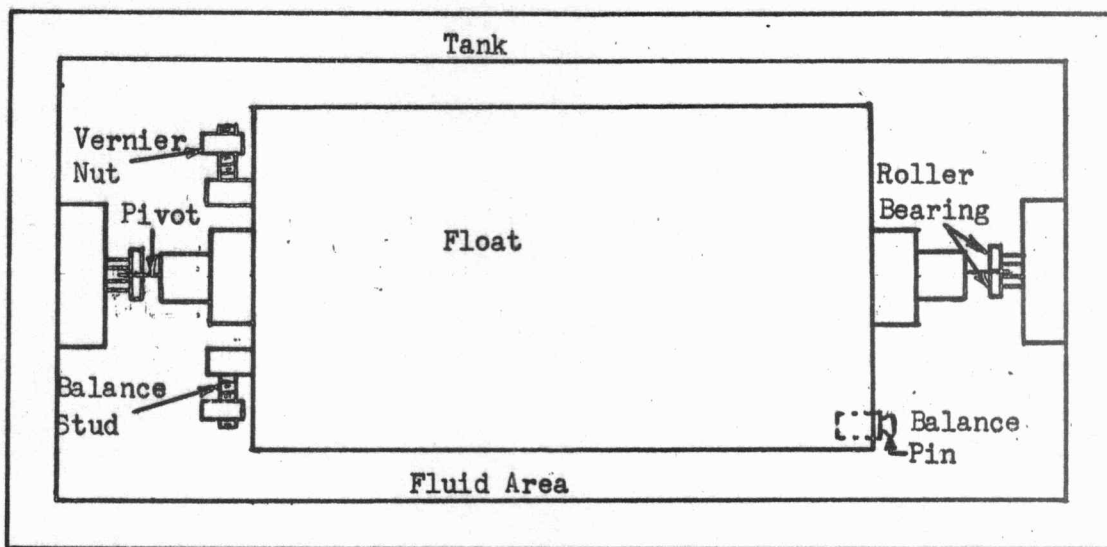


Fig. 9

Note: Float pivots rest on top of roller bearings when suspended in lighter Fluid and underneath bearings when buoyed in heavier Fluid.
For purpose of simplicity, only one balance pin is shown. In practice, several pins are installed on both ends of Float.

Longitudinal Balancing Fixture

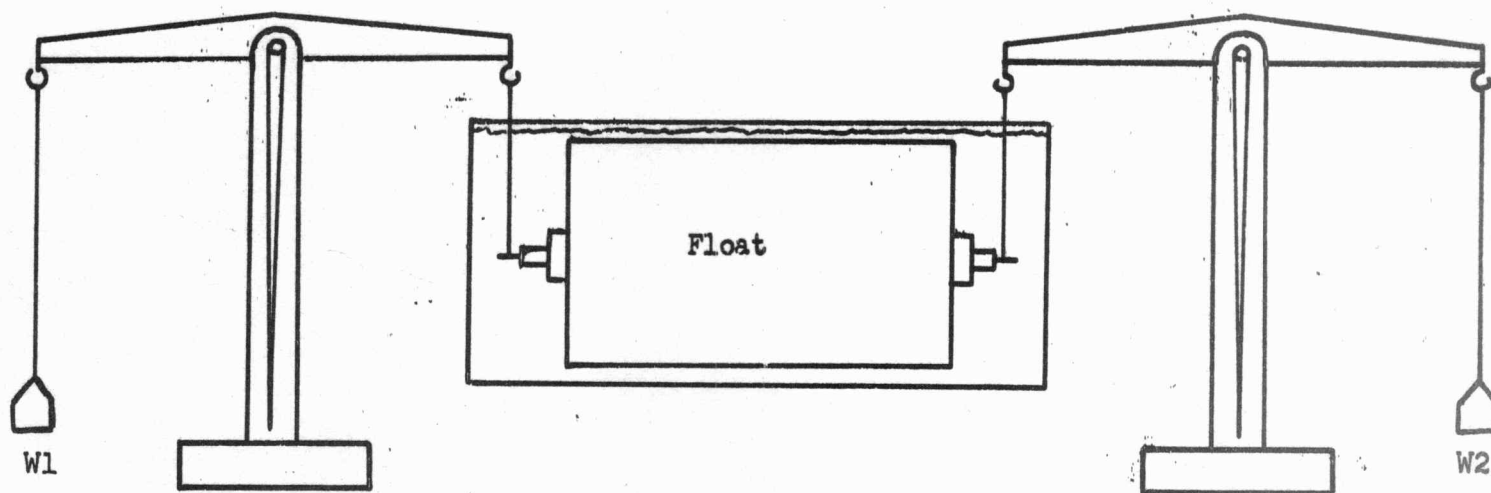
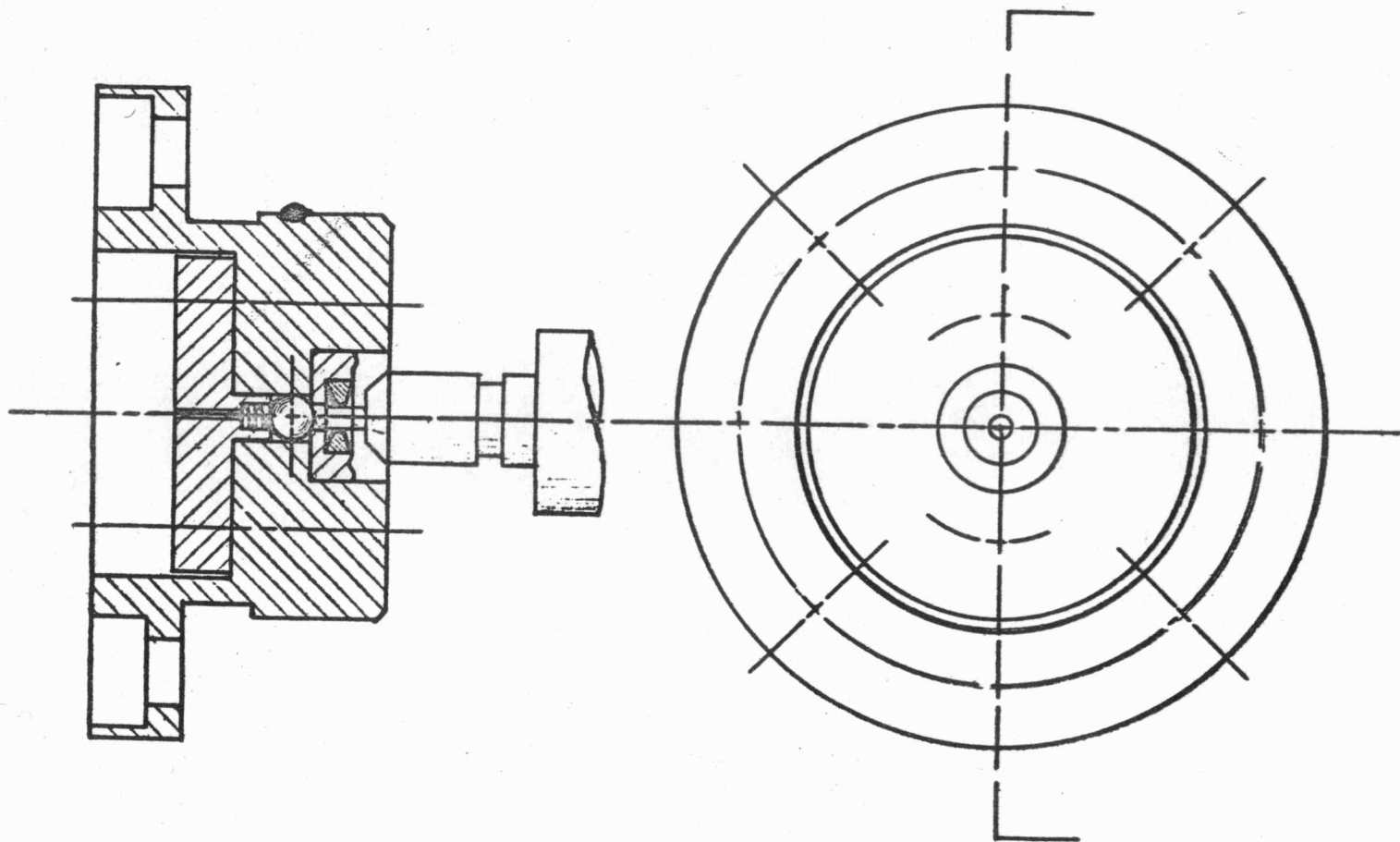
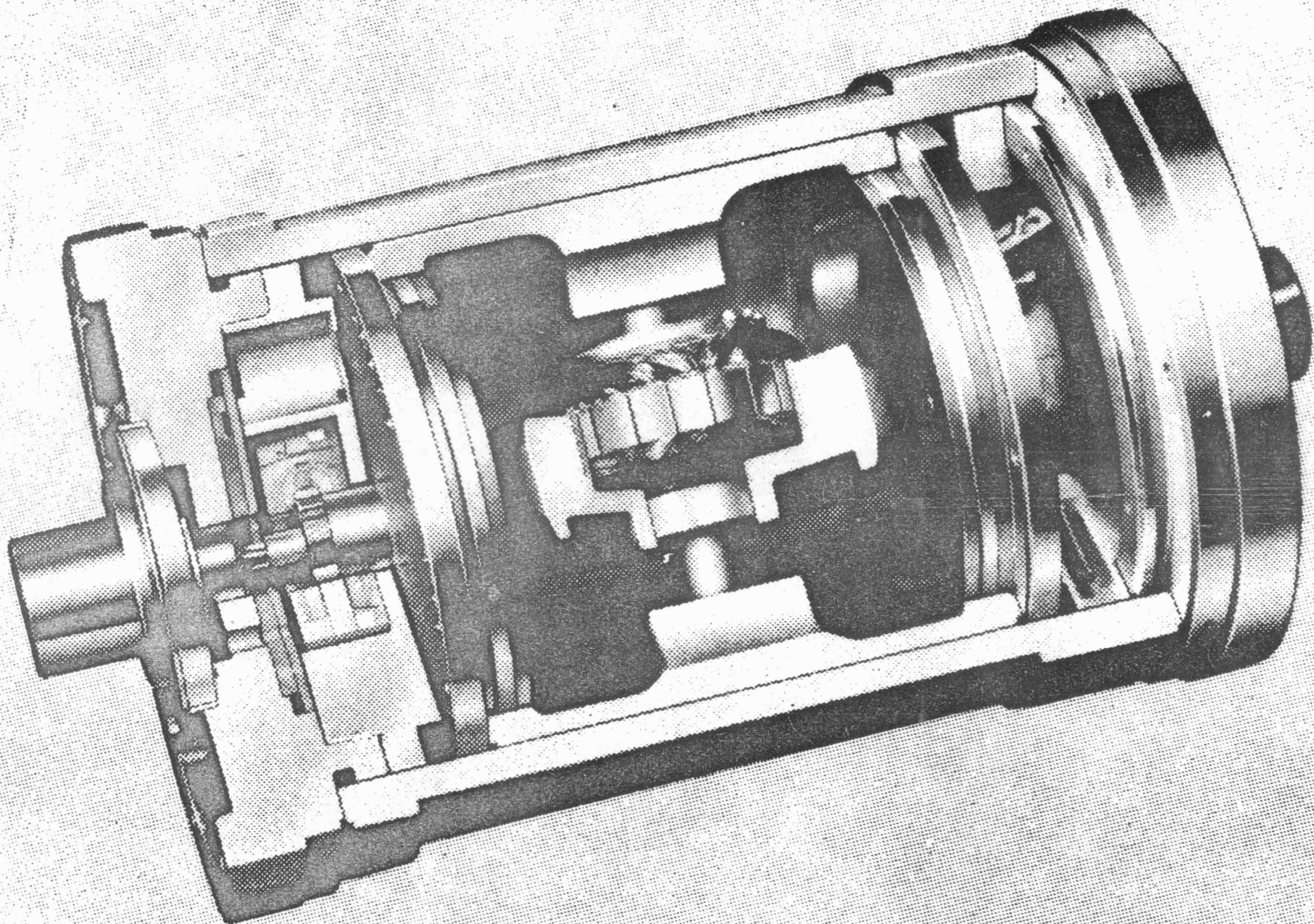


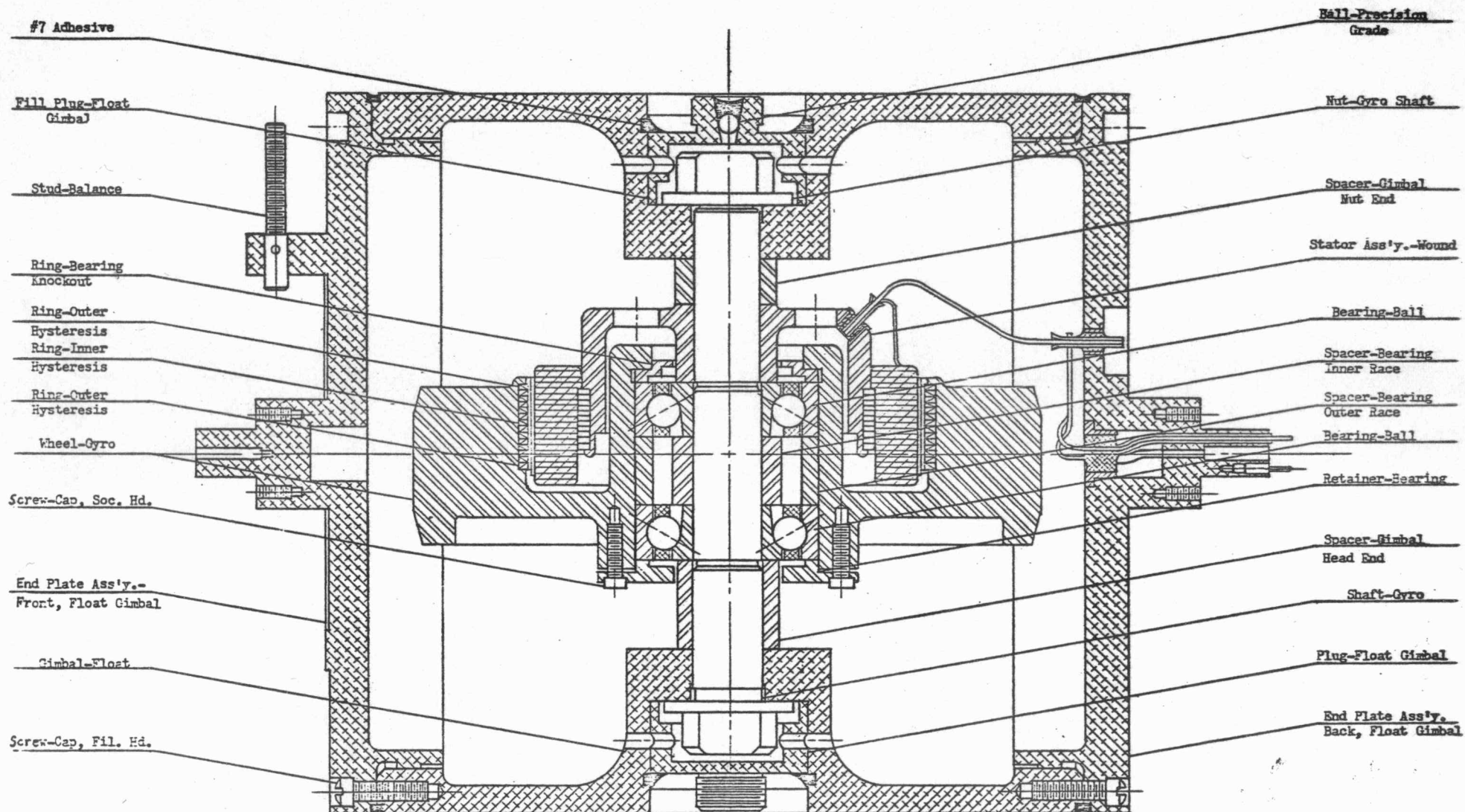
Fig. 10

Note: To obtain a perfect balance, W1 must equal W2.

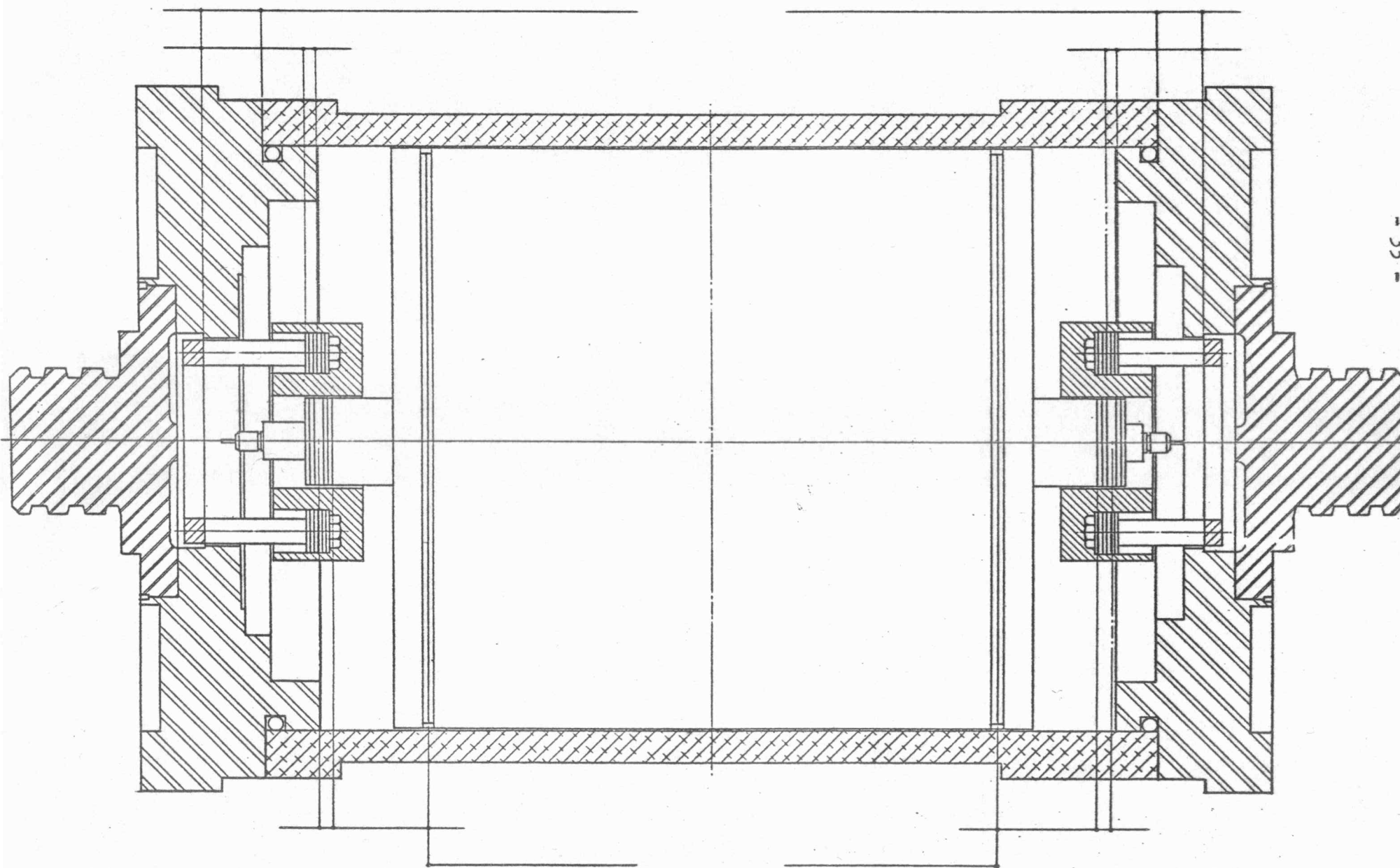


Jewel Bearing Assembly
1.0 x 107 Model II Rate Intergrating Gyro.





Float Assembly



- 35 -

1.0 x 10⁷ Model II Rate Integrating Gyro

to destroy rotational balance of the float. Fine balancing is again accomplished by vernier nut adjustment. Here also the total unbalance must be split between two opposite verniers.

VII. End Housing Assembly:

- A. The end housing assembly consists of two plastic baffles, power leads, four (4) expansion-contraction bellows, one metal baffle and a microsyn stator for each end housing.
1. Of the two plastic baffles, one is slotted to receive the wheel power leads, although not making physical contact with them, and the other acts as a cover for the flex leads. The baffles just described are part of the back end housing and also hold the T.G. terminals in place.
 2. The front end housing plastic baffles serve a similar purpose in that the S.G. terminals are anchored in them. In both cases the plastic baffles are placed into the end housings first.
 3. Wheel power leads are fitted into place and soldered.
 4. Four (4) bellows are emplaced in each end housing to absorb expansion and contraction of the damping fluid should there be a transient in gyro temperature.
 5. A metal baffle is positioned over that part of the assembly discussed thus far and fastened down securely with screws. This baffle protects the plastic part and holds the bellows in place.
 6. The microsyn stators are then mounted and secured in place with four mounting studs.

VIII. Jewel Bearing Assembly:

- A. Jewel Bearing Holder:

1. The jewel bearing spring is dropped into a drilled hole in the jewel holder and followed by a precision steel ball. It is this ball on which the end of the float pivot makes contact. A retainer is used to hold the ball and spring in place. The float pivot fits thru a hole in the jewel bearing and will make contact with the steel ball if the gyro experiences a longitudinal shift. Tolerances are allowed for the gyro to shift longitudinally along the OA to a very small degree. Ideally the pivots should never make contact with the steel ball but if contact is made the spherical surface of the ball describes a minimum contact surface with the pivot end.
2. A jewel bearing spacer, calculated in size to control float travel along the pivot axis, is then placed in the end housing to make up the entire jewel bearing assembly.

IX. Final Assembly:

- A. The front end housing is mated to the gyro main housing.
- B. The float is installed into the main housing taking care to engage the float stops in the stop holes provided in the face of the end housing.
- C. The back end housing, torque generator end, is mated to the gyro main housing.
- D. The jewel bearings are mounted to the end housings.
- E. The gyro case trunions are mounted to the outside of the end housings.
- F. Heater and sensor windings are installed.
- G. The gyro is filled with viscous damping fluid.

X. Microsyn Centering:

- A. Microsyns are centered to insure proper positioning of the microsyn rotor within the stator both translationally and rotationally and also to insure both microsyns are at a null simultaneously. Since the microsyn rotors have already been aligned, further alignment must concern itself with adjustment of the microsyn stator mounting studs.

1.0 x 10⁴ PENDULOUS INTEGRATING GYRO

<u>Part Name:</u>	<u>Number Required:</u>
Hysteresis Rings	- -
Gyro Wheel	1
Wheel Bearings	2
Gyro Shaft (SA)	1
Motor Stator	1
Wheel Fork	1
Float Shell	1
Microsyn Rotors	2
Microsyn Stators	2
Float Pivots	2
Float Balance Assembly	1 (Consists of 4 vernier nuts on 4 balance studs)
Jewel Bearings	2
Main Housing	1
Signal End Housing	1
Sleeve	1
Flex Leads	3
Aluminum Baffle	1

End Cap	1
Can	1
Sensor Windings	1
Heater Windings	1
Stop Pin	1

The following is an outline form of gyro assembly which closely follows actual manufacturing procedures:

I. Visual Inspection of all Parts:

- A. The same inspection procedures are followed as for the 1.0×10^7 Model II gyro.

II. Wheel Package Assembly:

- A. Hysteresis rings are mated to the gyro wheel.
 - 1. An interference fit exists between the wheel and the rings.
- B. Select and Install Wheel Bearings:
 - 1. Properly sized bearings are selected and fitted to the wheel. The wheel and bearings are centrifuged at 400 g's to remove excess oil and foreign material.
 - 2. Bearings are preloaded and run-up and run-down checks are made. Run-up checks and run-down checks are indicative of preload conditions of the wheel bearings.
- C. The wheel, bearings and motor stator are mounted to the gyro shaft. The assembly thus far comprises the wheel package. The wheel package is then mounted in the wheel fork.

III. Float Assembly:

- A. Matching Wheel Package and Fork to the Float Shell
 - 1. The wheel package and fork are fitted into the shell and the joint

is crimped at three equi-angular points about the joint circumference. The entire joint is then sealed by induction soldering.

2. Float Pivots are pressed into place in the ends of the float stud shafts and checked for concentricity about the float longitudinal axis.
3. Microsyn rotors are installed, aligned for symmetrical axis concentricity and firmly secured with two holding screws in each rotor.

B. Balance Assembly:

1. The balance assembly consists of a hub which fits over the float stub shaft on the signal generator end of the float, four balance studs which protrude from the hub at equi-angular points, and four vernier nuts which thread onto the balance studs.

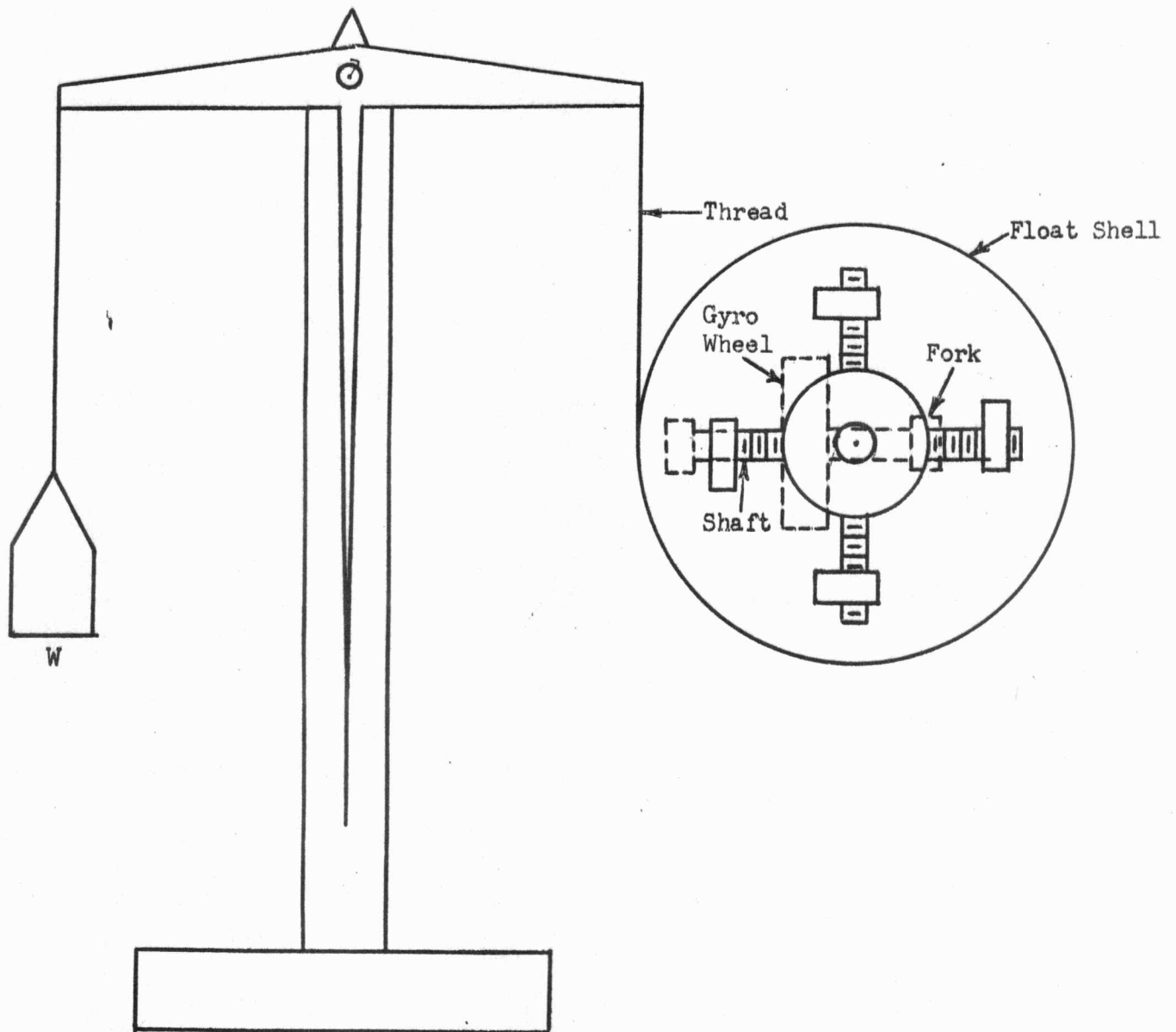
IV. Pendulosity:

1. The pendulosity of the gyro may be defined as a function of the torque produced about OA due to a precision unbalance along the SA and an acceleration along the IA causing the unbalance to act as a pendulum. Thus, the magnitude of the resultant torque about OA will depend on the degree of unbalance and the degree of acceleration. Since the unbalance is comprised of a mass and its displacement along the SA and since the mass is held constant, the determining factor involved is the distance the mass is displaced along the SA from actual center. This is accomplished by machining the fork end of the float, of which the fork is physically a part, such that the fork itself is displaced a given distance along the SA and thus holds the wheel package in this relative position also. In effect the float center of gravity is also displaced along the SA in the same direction as the wheel location. This is a coarse method of regulating pendulosity at best and a means

of critical adjustment to the value required is needed. The fine adjustment for locating the float e.g., is provided in the addition of the balance assembly. The vernier nuts are turned on the threaded balance studs to the point which provides the needed unbalance. Pendulosity is set for each gyro while it is sensing one g. by means of a thread wrapped about the float circumference in a direction which will oppose the unbalance. The end of this thread is then attached to a precision balance scale and the verniers are adjusted to balance the scale. (See Figure 11).

V. Final Assembly:

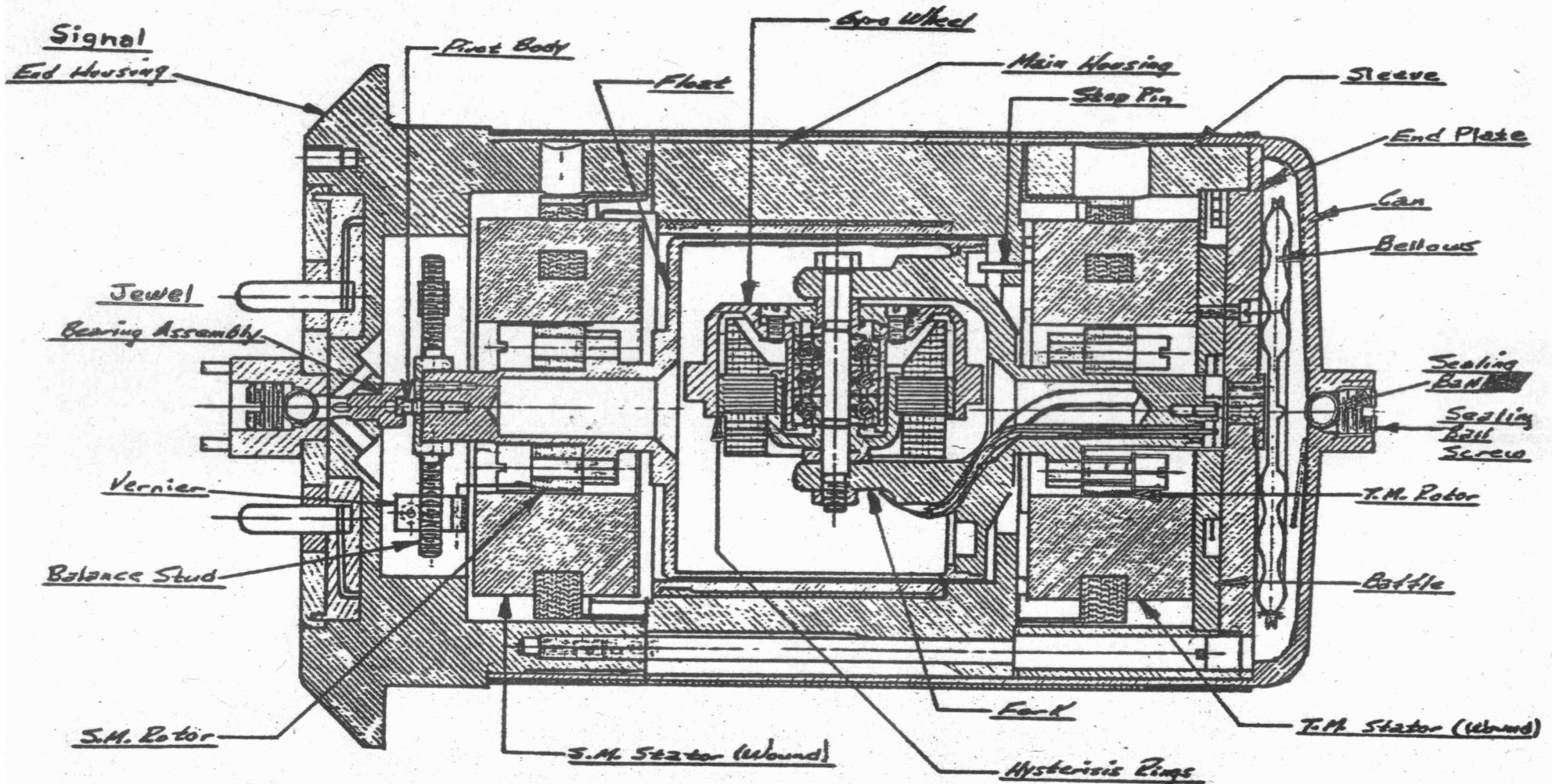
- A. Install float in the main housing.
- B. Fit signal end housing to the main housing.
- C. Install T.G. stator.
- D. Fit sleeve to the main housing.
- E. Install aluminum baffle.
- F. Install power leads and solder in place.
- G. Install end cap complete with jewel bearing assembly.
- H. Center microsins using the same method as used for the 1.0×10^7 Model II gyro.
- I. Install the gyro assembly into the can and cement the joint.
 - 1. The can fits over the gyro unit and butts to the signal end housing. One end of the can is closed except for a small recepticle provided for filling operations. This small tube is sealed after filling has been completed.
- J. Heater and sensor windings are installed.
 - 1. Heater and sensor windings are cylindrically shaped and fit over the can.
- K. The gyro is filled with viscous damping fluid.



Note: W represents desired pendulosity.

Pendulosity Adjustment

Fig. 11



1.0 x 10⁴ Model II-A Pendulous Integrating Gyro

25 IRIG 1.4×10^5 INERTIAL REFERENCE INTEGRATING GYRO and

25 PIG 0.6×10^5 PENDULOUS INTEGRATING GYRO

Note: The 25 PIG and the 25 IRIG gyros are physically identical except for their wheel assemblies. Therefore, all gyro parts and assembly for both gyros are given in one discussion except for the wheel assemblies where a differentiation will be made.

<u>Part Name:</u>	<u>Number Required:</u>
Gyro Shaft	1
Wheel Hub (IRIG)	1
Wheel Insert (IRIG)	1
Hysteresis Rings	- -
Inertia Rims (IRIG)	2
Wheel Bearings	2
Preload Nuts	2
Preload Bushings	2
Motor Stator	1
Float Hemispheres	2
Float Gimbal	1
Microsyn Rotors	2
Microsyn Stators	2
Float Pivots	2
Damping Blocks	2
Printed Circuit Microsyn Leads	2
Printed Circuit Shields	2
Jewel Bearings	2
Bellows End Caps	2

End Housings	2
Flex Leads	3
Baffles	2
Flex Lead Plates	2
Main Housing	1
Main Cover Shroud	1
End Cover Shrouds	2
Sealing Balls	2
Sealing Ball Screws	2
Balance Screws	8
Balance Springs	4
Thermistor	1
Pendulous Ring (PIG)	1
Wheel Web (PIG)	1
Wheel Hub (PIG)	1
Pivot Adjustment Screws	8

The following is an outline form of gyro assembly which closely follows actual manufacturing procedures:

I. Visual Inspection of all Parts:

A. The procedures are similar to previously mentioned gyros.

II. Wheel Package Assembly:

A. Bearing selection and preload members installed.

1. Bearings are selected for proper fit to wheel shaft and wheel hub.

The bearings are pressed into place in the wheel hub and the gyro shaft is fitted thru the bearings. The preload nut is dropped over--

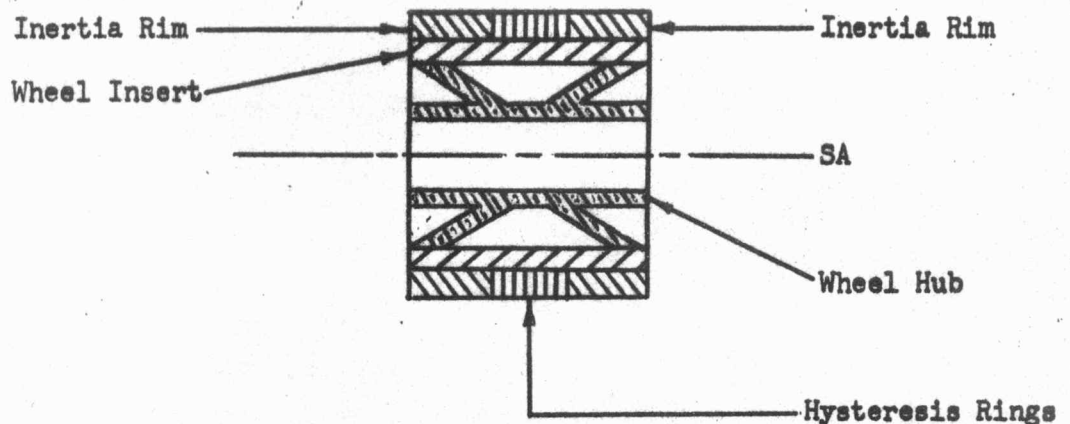
the shaft to fit interface with the bearings. The preload bushing is then turned into the preload nut to insure smooth thread operation. The wheel bearings are centrifuged at 2,000 g's to remove excess oil and foreign material.

B. Insert Installation:

1. The wheel insert fits over the wheel hub with interference between the insert I.D. and the wheel hub O.D. The wheel insert is cylindrically shaped and is of the same dimensional width as the wheel hub.

C. Hysteresis Ring and Inertia Rim Installation:

1. The hysteresis rings are fitted over the wheel insert face in the plane perpendicular to the wheel spin axis and in the center of the circumferential face. The two inertia rims fit over the insert face also and butt to the edges of the hysteresis rings on either side of it. The total face width of the hysteresis rings together with the two inertia rims is equal to the face width of the insert. (See Figure Below).



D. Preload Adjustment:

1. Once the entire wheel is assembled, it is necessary to set in the proper bearing preload to ensure specified bearing life and operation

This is accomplished by wrapping a thread several turns around the hysteresis rings with a given weight attached to the opposite end of the thread. The weight is allowed to fall, thus rotating the wheel and preload is adjusted until the desired wheel RPM is obtained. This method of setting preload is only an approximation, however, and further adjustments are necessary at a later stage of assembly.

III. Float Sphere Assembly:

A. Motor Stator Installation:

1. The motor stator is pressed into the heated float gimbal and cemented in place. When the gimbal cools an interference fit remains between itself and the motor stator.

B. Float Pivot Installation:

1. The float pivots are threaded into the ends of the float stub shafts on each end of the float gimbal. Four pivot adjustment screws are threaded into place for each pivot and uniformly tightened while checking pivot concentricity about the float gimbal longitudinal axis.

C. Plus SRA Float Hemisphere Assembly:

1. The plus SRA hemisphere is threaded onto the plus SRA end of the gyro shaft and cemented in place.

D. Minus SRA Float Hemisphere Assembly and Wheel Package Installation:

1. The wheel package assembly is installed into the float assembly and the minus SRA hemisphere and bushing are assembled over the minus end of the gyro wheel shaft. Stainless steel balance weights are assembled into the minus SRA and IA ports and aluminum balance

weights are assembled into the minus SRA and IA ports. The SRA ports are located in the float hemispheres along the SRA and the IA ports are located in the float gimbal along the IA. The float assembly is then mounted on pivot rests and two balance arms of equal length and weight are installed opposite each other along the SRA in threaded holes in the float gimbal shaft. A pan is placed on the end of each balance arm and weights are added to the lighter pan until the float assembly balances on the pivot rests. From the required weight necessary to balance the float assembly, the proper shim size is determined and a shim of the prescribed size and weight is installed under the plus SRA bushing and cemented in place. The minus SRA hemisphere is then mounted in position and cemented in place.

E. Bearing Preload Adjustment:

The float is mounted in a fixture that will maintain an atmosphere of helium gas. The wheel terminals are connected to a two phase, 800 cycle power source and the wheel is brought up to synchronous speed. While maintaining a float temperature of 137° fahrenheit, the run-down time of the wheel from synchronous speed is recorded. If the run-down time does not correspond with the specified value, the bearing preload is adjusted by means of the preload nut while the wheel is running and run-down times are again taken. This procedure is repeated as necessary until proper bearing preload is obtained. The minus SRA bushing is then cemented and the float is degassed and filled with helium.

F. Microsyn Rotor Installation and Alignment:

1. The microsyn rotors are wrung onto the tapered gimbal stub shafts and aligned such that the flat surfaces are parallel to the pitch diameter of the IA balance port threads and the S.G. and T.G. rotors are in line across the flats. The microsyn rotors are then secured in place with cement.

G. Longitudinal Balancing:

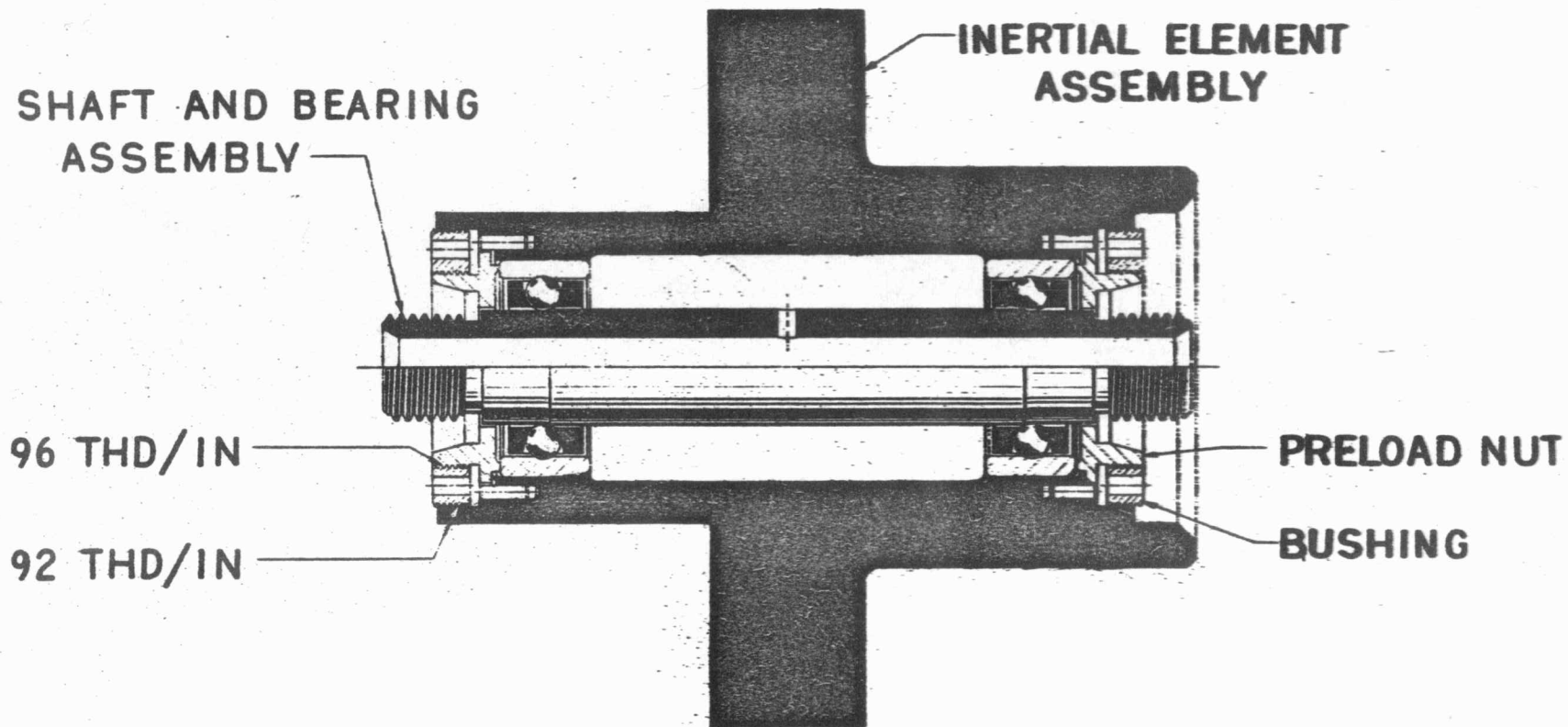
1. After determining the weight necessary for the proper balance, weights of the proper size are threaded into the float gimbal stub shafts in the tapped hole provided. The balance weight hole on the S.G. end of the gimbal stub shaft is drilled at right angles to the stub shaft and also at right angles to the balance weight hole on the T.G. end of the gimbal stub shaft. In other words, one balance weight hole is parallel to SRA and the other balance weight hole is parallel to the IA. Longitudinal balancing is done in a fluid possessing a density very similar to the damping fluid used to fill the unit.

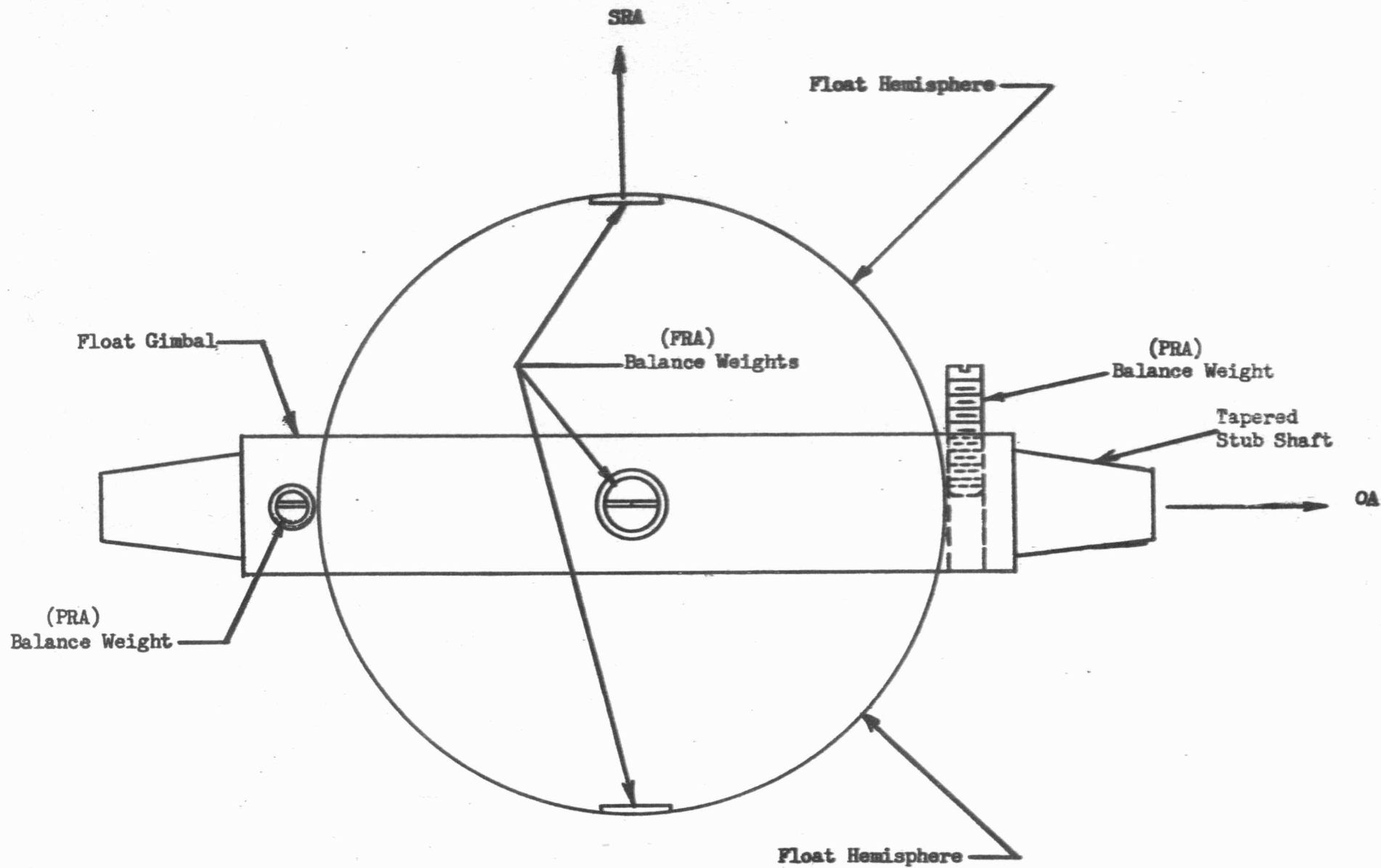
H. Rotational Balancing:

1. The float is installed in a flotation tank and the sized balance weights that were installed during longitudinal balancing are adjusted along their axis for the proper rotational balance. (See Figure 12). The balance screws used for this operation are referred to as the PRA (Preliminary Rotational Adjust) balance weights. By definition, the term PRA indicates that a coarse balance is obtained thru adjustment of the PRA balance weights and that additional adjustments are necessary to reach an accurate state

WHEEL ASSEMBLY

25 PIG MOD 1





25 PIG or 25 IRIG Float Assembly showing
Balance Weights Configuration

Fig. 12

of rotational balance. This critical area of balance is reached thru employment of the FRA (Final Rotational Adjust) balance weights provided. The FRA balance weights, of which there are eight in number, are located in the balance ports on both ends of the SRA and IA. Two FRA balance weights are threaded into each port and are separated by a balance weight spring. Adjustment of the FRA balance weights along SRA and IA constitutes final rotational balancing of the gyro float. (In the case of the 25 PIG unit, the balance screws are adjusted to obtain the proper pendulosity as required.)

IV. End Housing Assembly:

A. Terminal Seal Assembly:

1. The terminal seal is fitted into the end housing and soldered in place.

B. Microsyn Stator Assembly:

1. The microsyn stator is fitted into the end of the end housing and care is taken to insure proper bottoming of the microsyn stator so cocking does not occur.

C. Printed Circuit Assembly:

1. The printed circuit is installed in the end housing and the terminals are affixed to the printed circuit and soldered.

D. Encapsulation:

1. Following assembly of the entire end housing, it is encapsulated with potting compound to physically seal in place all the assembled parts within. The potting compound also serves as an insulator for the electrical circuitry within the end housing assembly.

V. Final Assembly:

A. Flex Leads:

1. The flex leads are installed in the flex lead plate and soldered in place.

B. The T.G. end damping block is installed in the main housing.

C. A flex lead baffle is installed in the T.G. end of the main housing and secured in place with two screws.

D. The gyro float assembly is fitted into the main housing.

E. A damping block and a flex lead baffle are assembled into the S.G. end of the main housing and secured in place.

F. The flex lead assembly is installed in the flex lead baffle and soldered to the float assembly.

G. Both end housing assemblies are fitted to the main housing and secured in place.

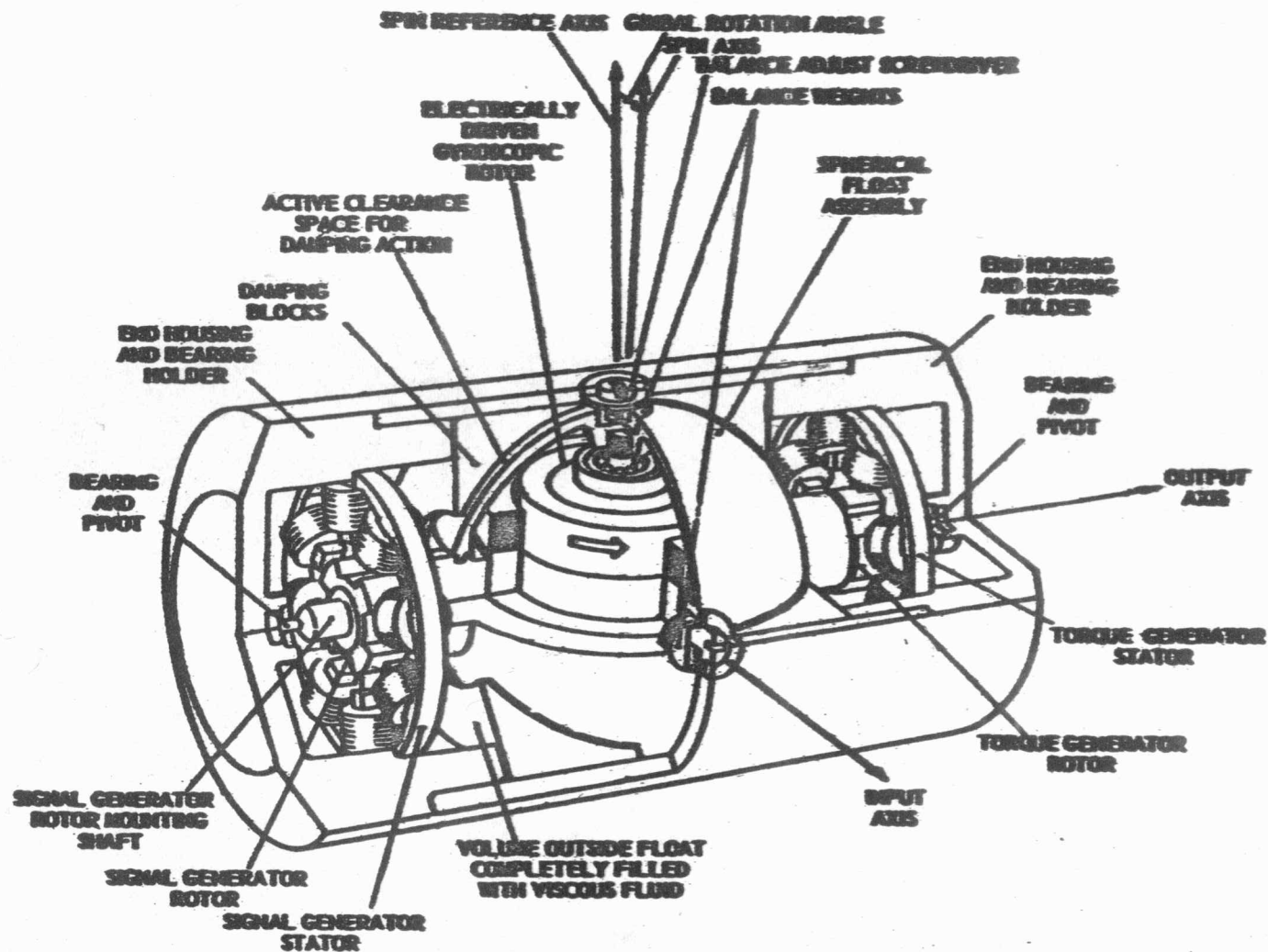
H. Both jewel bearing assemblies are assembled to the end housings.

I. Similar processes as employed for the 1.0×10^7 Model II unit are followed to seal the 25 FIG and 25 IRIG units.

Note: Approximately the same procedures are used to assemble the wheel package for the 25 FIG unit as were used for the 25 IRIG unit. Refer to the list of part names for nomenclature differences.

VI. Filling Procedure:

A. After the unit has been pre-evacuated for 120 hours, a fixture bellows adapter is mounted on the gyro for each bellows. The fixture bellows adapters are used to compress the expansion-contraction bellows a predetermined amount and to maintain their contracted



Generalized pictorial schematic of the 25 FIG unit.

condition throughout the filling operation. This is done to insure a margin of safety in the event the gyro experiences excessive cooling after it has been filled. The gyro is then evacuated again for a 2 hour period and after this evacuation period the gyro is filled with viscous damping fluid. Once the filling operation has been completed, both ends of the gyro are sealed with sealing balls and sealing plugs.

Note: At the present time the 25 PIG and 25 IRIG units cannot be classified as cold gyros and therefore must be kept at a temperature of 135^{+5}_{-1} degrees fahrenheit for the life of the gyros.

2FEG-2C 2.0×10^6 FLOATED BERYLLIUM GYRO

<u>Part Name:</u>	<u>Number Required:</u>
Working Capacitors	8 (4 for each microsyn)
Wheel Bearings	2
Gyro Shaft	1
Bearing Spacers	2
Motor Stator	1
Hysteresis Rings	- -
Gyro Hub	1
*** Gyro Rim	1
Gyro Float Gimbal	1
Gyro Float Shell	1
Balance Mounts	4
Balance Paddles	4

Balance Ring	1
Microsyn Rotors	2
Microsyn Stators	2
Float Pivots	2
Power Leads	3
Power Lead Baffle	1
Balance Forks	2
Bellows	2
Jewel Bearing Assemblies	2
End Housings	2
Main Housing	1
Stop Pin	1
Microsyn Shields	2
Sealing Balls	2
Sealing Screws	2

The following is an outline form of gyro assembly which closely follows actual manufacturing procedures:

I. Wheel Package Assembly:

A. Bearing Selection, Evaluation and Calibration:

1. The bearings which are to be used in the wheel package are chosen in pairs to insure proper matching of inner diameters. The bearing set is centrifuged at 400 g's to remove excess oil. A low speed dynamometer is used to obtain torque traces of the bearings under the desired preload conditions. This is done to determine whether or not the bearings are acceptable for further assembly into the gyro unit wheel package.

B. Gyro Wheel Assembly and Balance:

1. The gyro wheel hub is heated to receive the hysteresis rings for an interference fit. The gyro wheel rim is then heated and fitted over the wheel hub. Since the wheel hub is constructed from beryllium which is quite light material, the wheel rim must be constructed of a heavier material to gain the proper inertial characteristics from which the desired angular momentum (H) can be obtained.

Next, the bearing package consisting of an inner race spacer, an outer race spacer and the bearings is assembled in bearing tools. The gyro wheel is heated and the bearing package is assembled to the wheel. The bearings are then given the desired preload in a balancing fixture and the wheel is run to synchronization. The degree of unbalance is determined and balancing procedures are performed. These consist of extracting wheel material at the points of unbalance until the wheel is symmetrically balanced.

II. Gimbal Assembly:

- A. A float-balance ring of a predetermined weight value is utilized to act as a longitudinal balance correction for the float. It is simply a metal ring which is fitted over the float stub shaft on the signal generator end of the float. Heat is applied to the float-balance ring before assembly to the stub shaft so as to produce an interference fit with the stub shaft.
- B. Assembly of Wheel Package to the Gimbal:
 1. The wheel spacers, gyro wheel and motor stator are assembled

to a stub shaft and inserted into the gimbal. Next, the stub shaft is removed and the final shaft inserted thru the gimbal and the wheel package to complete the gimbal and wheel package assembly. The shaft nuts are tightened alternately to provide the desired preload and to coarse balance the assembly rotationally.

III. Float Assembly:

A. Shell and Gimbal Assembly:

1. The float shell is heated and slipped over the gimbal. After cooling, an interference fit remains between the shell and gimbal. The circumferential joints are then sealed.

B. Pivot Installations:

1. The pivots are pressed into the pivot holes on each end of the float and cemented in place. After the adhesive has cured, pivot concentricity to the float longitudinal axis is checked.

C. Balance Mount Installation:

1. The balance mounts are positioned on the T.G. end of the float and secured in place with mounting screws and adhesive. The balance paddles are then poised and threaded into the balance mounts. Poising of the balance paddles is accomplished by insuring symmetrical balance about the longitudinal axis of the paddle.

IV. Float Balancing:

A. Longitudinal Balancing:

1. The longitudinal balancing is accomplished by adding weight slugs

to either end of the float shell in the slot provided in each end of the shell end circumference. It is necessary to add slugs to compensate for the unbalance present by proportioning the necessary weight to two or more slugs. The slugs are then positioned in the slots at equiangular intervals to prevent destruction of the existing degree of rotational balance. See Figure 13

B. Rotational Balancing:

1. The four balance paddles, which are mounted at equiangular intervals about the float end circumference, are adjusted by turning their threaded portion thru the balance mounts to position the paddles at a point which will rotationally balance the float. See Figure 14.

V. End Housing Assembly:

A. Microsyn Stator:

1. The microsyn stators are mounted in each of the end housings and cemented in place.
2. The shield assemblies are mounted on the microsyn stators and cemented in place.
3. The wheel power leads are soldered to the power lead standoffs and the standoffs are assembled to the end housings. The entire internal assembly is then potted to secure the parts in place and to provide insulation of the electrical circuitry.

VI. General Assembly of the Gyro Unit:

A. Power Lead Baffle Assembly:

1. Power lead ribbons are assembled to a soldering fixture. A baffle collet is then soldered to one end of the ribbon

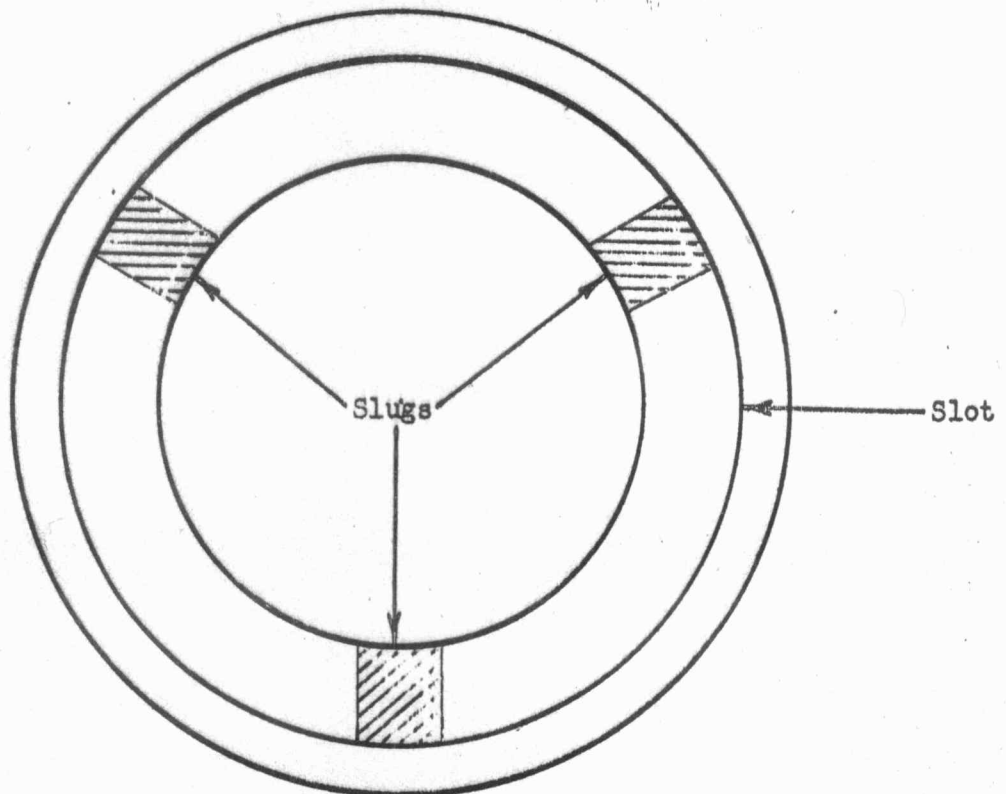


Fig. 13

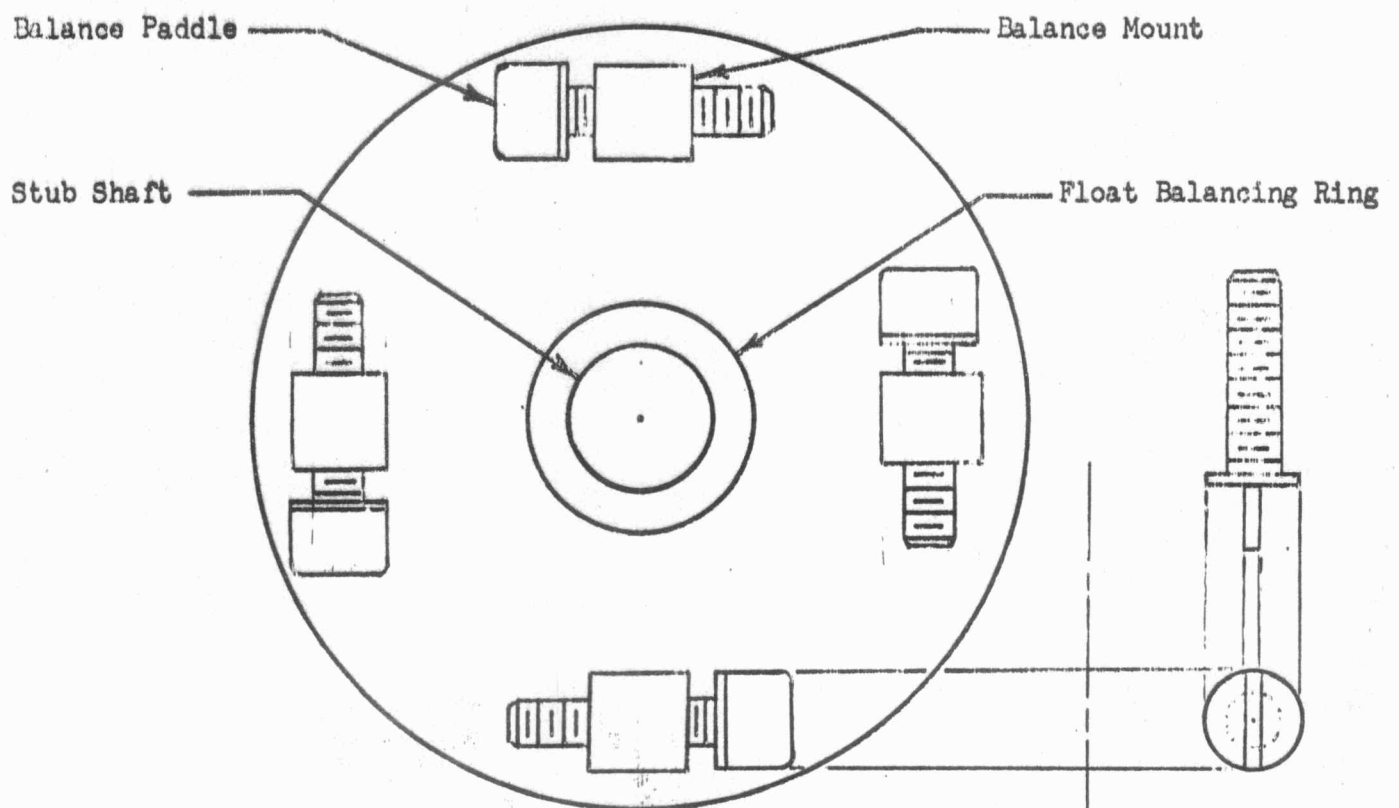


Fig. 14

and a gimbal collet is soldered to the other. The baffle collects are then cemented to the baffle.

B. Jewel Bearing Installation:

1. The jewel bearing assembly is mounted on the end housing.
- C. The back end housing is mounted to the main housing and the balance forks are assembled to the main housing. Care must be exercised to align the balance forks such that they will receive the balance paddles without interference when the float is fitted into the main housing
- D. The microsyn rotors are mounted to the float stub shafts and aligned.
- E. The float assembly is mounted in a fixture and the main housing with the attached back end housing is lowered over the float while checking to insure proper seating of the float pivot in the jewel bearing.
- F. The unit is turned over such that the signal end is up and the baffle retainer snap ring is fitted in place inside the main housing.
- G. The power lead baffle assembly is mounted to the baffle retainer and the gimbal collets are pressed over the power lead posts.
- H. The front end housing is assembled to the main housing to complete the assembly of the gyro unit.
- I. The gyro unit is then evacuated and filled with the appropriate damping fluid. After filling procedures are completed, the unit is sealed with the sealing balls and sealing ball screws.
- J. Microsyn centering is accomplished by utilizing the magnetic sus-

pension system. Radial voltages are noted when corresponding pole pairs of the T.G. and S.G. are shorted out allowing the float pivots to come to rest against the jewel bearing. A value of center position in terms of radial voltages is determined and the magnetic suspension working capacitors values are established to obtain the desired float position.

1.0×10^7 RATE INTEGRATING GYRO (Mod. VI-A)

- I. Due to their classified nature, assembly procedures for the Model VI-A gyro must be omitted from this booklet. Reference may be made to Engineering Specification ES-3737 for assembly procedures. It may be noted here that except for certain normalizing for particular systems applications, the Model VI-A is constructed and assembled similar to the Model II. Two factors which may be mentioned here that are considered major differences from the Model II, are the employment of an outer heater jacket or cover on the Model VI-A and also a difference in gyro motor requirements.

3.0×10^7 RATE INTEGRATING GYRO (Mark VII-B)

1.0×10^7 RATE INTEGRATING GYRO (Model VIII)

- I. These gyros are currently in a production stage where assembly procedures are not available or firm. The only purpose in mentioning them here is merely to acquaint the reader with their existence as gyros within the AC Spark Plug gyro program.

III. GYRO TESTING:

The following discussion is concerned with the area of gyro testing. Each gyro is subjected to test to insure proper operation and quality. Testing procedures differ slightly for the individual gyro types or models and will be discussed separately for each type or model.

1.0 x 10⁷ Mod. II RATE INTEGRATING GYRO

I. Resistance and Continuity Check:

- A. Gyro wiring is checked for open circuits or shorted circuits.
- B. Resistance values for the heater and sensor windings are checked to establish their adherence to specifications.

II. Microsyn Centering:

- A. Microsyn centering is checked by raising the gyro temperature and allowing the float to "sink" to the point where pivot contact is made with the jewel bearing. The gyro is positioned with the SRA vertical for this check. Both T.G. and S.G. output is monitored for plus SRA up and plus SRA down. Difference in plus and minus values indicates the amount of translational movement of the microsyn rotor within the stator and whether or not the microsyn is centered properly.

III. Flotation:

- A. Flotation of the gyro is necessary to insure minimum friction between the pivots and the jewel bearings. This is accomplished by adjusting the gyro temperature, which will control the fluid density, to a point where the float neither sinks nor becomes excessively buoyant. Flotation will occur at a point where the T.G. and S.M. outputs are midway between Microsyn Centering values. Gyro temperature is controlled by controlling the resistance of the sensor winding. The proper sensor resistance is noted and

recorded. Gyro operation, while in use and for all further testing, is performed at the flotation temperature derived from this check.

IV. Gravity Transients:

- A. The gravity transient check is performed to insure absence of either air bubbles in the damping fluid or damping fluid within the float cavity. Tests are taken at four positions; plus SRA both up and down and plus IA both up and down. OA is horizontal at all times and the gyro wheel is not rotating. With these conditions met, no outside forces other than gravity will act upon the gyro. Excitation current is supplied to the control winding of the T.G. to hold the float at a null position. The amount of current required to hold this null is recorded graphically and any unbalance due to either of the causes previously mentioned will cause a current fluctuation which can be read from the graph.

V. Float Unbalance:

- A. To determine any rotational float unbalance, the float is driven from null to a point of a given S.G. output and then driven back with a constant input to the T.G. This is done in both a plus and minus direction from null and the time required to return to a null is recorded. Any unbalance will be indicated by an excessive return time differential between the plus and minus rotational direction.

VI. Wheel Run-up:

- A. The gyro wheel is excited and run to synchronous speed.
- B. The starting and running current are checked.

- C. The run-up and run-down times are checked: These will be an indication of bearing ~~friction~~ and preload.
- D. The voltage where the wheel drops out of synchronization is noted as the voltage is decreased and the wheel is running down.
- E. The wheel is checked for proper direction of rotation.
- F. The gyro is checked for a proper S.G. null after the wheel is at synchronous speed.
- G. Heater power drain is observed after wheel is at synchronous speed.
- H. Heater cycling time is checked, both on and off time.

VII. Tumbling Test:

- A. Since it is impossible to manufacture a perfect gyro, it becomes necessary to test the gyro to determine the degree of inaccuracy present due to a form of unbalance. Generally there are three different types of unbalance to be considered. These are mass unbalance, residual unbalance, and compliance unbalance. The first of these, mass unbalance, can be contributed to an accumulation of minor machining and assembly inaccuracies but isn't of an incurable nature since a means of adjustment has been provided to neutralize the unbalance in rotation by means of balancing pins and vernier nuts.

The second type of unbalance mentioned, residual, can be contributed to a combination of torques applied about the OA from flex leads and microsyn reaction qualities. The torque applied due to flex leads can be compensated for by applying a constant current into the T.G. to oppose this torque once the compensation necessary has

been determined during the tumbling test. Microsyn reaction qualities can only be controlled thru strict adherence to good manufacturing procedures and quality control.

The third type of unbalance to be discussed, compliance unbalance, is the only one which cannot be compensated for to any great degree. Compliance unbalance is due to inherent material ability to retain its center of gravity thru restriction of plastic flow, or in other words, its isoelectric qualities. Compliance unbalance may also be due to a shift within the floated unit such as a movement of wheel bearing orientation from the original position. This might be caused in part by oil working its way between the bearings and spacers in excessive quantities, hence the reason for centrifuging the wheel bearings prior to assembly. One method of holding compliance unbalance to a minimum would be adherence to strict assembly procedures and material selection.

A tumbling test will indicate how much and of which type of unbalance is present in the gyro. The test table is positioned such that the table rotational axis is parallel to the earth's axis of rotation. The table is driven at a constant rate and the gyro, thru closed loop between the S.G. and T.G., is allowed to hold itself at a null while the torquing current required to hold a null is recorded graphically. Each run consists of the table being driven thru three complete revolutions in both CW and CCW directions. Runs are also made with the gyro in different attitudes in respect to the table plane. A Fourier Analysis is done on the graph trace to distinguish the type of un-

balance from each other and their magnitudes. After compensations necessary for mass unbalance correction have been performed, a final tumbling run is done to determine ultimate gyro quality.

VIII. Servo Test:

- A. The purpose of a servo test is to determine how well the gyro is able to maintain an accurate reference from the original attitude. The degree of inability of the gyro to perform this task is referred to as Drift Rate. Again, the table is positioned such that its rotational axis is parallel to the ERA (earth's rotational axis). The gyro is positioned on the table in an attitude such that its IA is coincident with the table rotational axis to impress the torque due to earth rotation entirely about the IA. The S.G. output is applied to the table drive servo motor so as to drive the table at a rate proportional to the output torque, or gyroscopic torque, produced by the gyro. A theoretically perfect gyro, being space referenced, would cause the table to rotate thru one complete revolution in an exact twenty-four hour period since the earth makes one complete revolution about ERA in the same period of time. For an actual gyro, the table does not rotate at sidereal rate. This is due to the effects of unbalance torques about the OA of the gyro that add to or subtract from the torque produced by the rotation of the earth, depending upon the direction of unbalance. If the table rate is measured with respect to the earth and the earth rate subtracted, the torque about the OA of the gyro due to unbalance torque may be calculated as a function of gravity and the angle of table rotation with respect to a given zero reference. The table rate

can be measured by a photoelectric device triggered by a beam of light passed by a graduated glass dial mounted concentric with the table rotational axis. The output of the photoelectric scale reader is used to trip an elapsed time recorder. Thus, the average rate of the table for any given angular rotation of the table may be calculated by subtracting the times at which the points occurred on the elapsed time recorder.

The unit to signify angular velocity is MERU (milli-earth-rate-unit). The angular velocity of the earth, which is the most precise readily available rate, is a convenient unit of measurement in testing gyros. By definition, if the angular velocity of the earth is one ERU (earth-rate-unit), then a MERU is one-thousandth of the earth rate. Hence, to convert a given rate into MERU, divide the given rate by earth rate and multiply by 1000.

In the discussion of gyro performance and gyro design, it is desirable to convert easily from rate units to torque units. Since the gyro precessional torque about the OA is equal to the angular momentum (H) of the gyro wheel multiplied by the angular velocity (ω) about the IA, an angular velocity of one ERU about the IA results in one ERT (earth-rate-torque) applied about the OA of the gyro.

<u>EARTH RATE UNITS</u>			<u>TORQUE UNITS</u>	
1 ERU	-	15 deg./Hr. - - - - -	$HW_{(I-E)}$	dyne-cm
1 MERU	-	.015 deg./Hr. - - - - -	$HW_{(I-E)}$	dyne-cm
			1000	

Where: H = Angular momentum of the gyro wheel in
gram-cm²/sec.

$W(I-E)$ = Angular velocity of the earth in respect
to inertial space.
= 7.2722×10^{-5} rad./sec. measured in sidereal
time

1.0×10^4 PENDULOUS INTEGRATING GYRO

I. Resistance and Continuity Check:

A. Same as for 1.0×10^4 Model II Rate Integrating Gyro

II. Microsyn Polarity and Null Check:

- A. The gyro is positioned on the table such that plus OA is horizontal and ~~pointing~~ West, and plus SRA vertical down. The S.G. is excited and the table is rotated CW about OA. The S.G. output to an oscilloscope is monitored to determine microsyn polarity. The oscilloscope will indicate the phase of the S.G. output for the particular rotation about OA of the gyro.
- B. The gyro is checked for a proper null voltage.
- C. S.G. voltages at the float rotational stops are checked.
- D. The gyro is checked for smooth float rotation.

III. Gyro Wheel Power and Phasing Check:

- A. The current required to run the gyro wheel to synchronization is noted. This is used as an indication of bearing preload conditions.
- B. Both run-up and run-down time of the gyro wheel is checked. This is also an indication of bearing preload conditions.
- C. The gyro wheel is checked for the proper direction of rotation. This is accomplished by observing the gyro wheel excitation for

the proper phase lead-lag characteristics.

IV. Damping Coefficient (CD) Check:

- A. The gyro is positioned with plus OA horizontal and plus SRA down. The wheel is allowed to reach synchronous speed and the float is torqued until a S.G. output of 1.0 volts is reached. The time required for the float to return to a point where the S.G. output voltage is 200 mv is recorded. The Damping Coefficient is calculated using the formula:

$$C_d = P \times 0.6213 \times T_{avg}.$$

Where

P = Pendulosity

T_{avg} = Average return time for the float.

The sensor resistance is adjusted until the proper gyro temperature is reached to provide the required damping.

V. Friction Level Check:

- A. The gyro float is torqued about its OA while float movement is observed thru S.G. output voltage. The time required and the condition of float movement is indicative of friction level between jewel bearings and float pivots.

VI. Float Travel Check:

- A. The gyro float travel is checked by comparing S.G. plus and minus stop voltages. S.G. sensitivity is obtained by measuring the S.G. output voltage at both plus and minus 4° of float rotation and taking $1/4$ the average of the two voltages.

VII. Tumbling Test:

- A. The gyro is positioned on the table such that the IA is coincident with the rotational axis of the turntable. The table is rotated at

a fixed rate of 270 degrees per hour. Table position is indexed to a recorder graph every 10 degrees. The torquing current is recorded on the graph where it is graphically converted to read in terms of dyne-cm of torque. The table tilt angle is adjusted for each test to approximately balance the gyro precessional torque.

Torque records are analyzed on a 36 point basis for average terms and first harmonics. Maximum deviation from the average on each run is recorded as tumbling threshold. Harmonics are assumed to be errors in alignment of the gyro to the table and are subtracted from the analyzed recording. An additional deviation from the average is computed for each run of each test and the larger of these deviations is known as Compensated Tumbling Threshold. A point for point repeatability is done by determining the difference between the first and second revolutions for each test. The larger of these is known as Tumbling Repeatability.

VIII. Servo Test:

- A. With the gyro positioned on the turntable such that the IA is coincident with the table rotational axis, the gyro is allowed to drive the table thru three uninterrupted revolutions. This is done with the gyro sensing $3 \times 10^{-3}g$'s and also for $1 \times 10^{-2}g$'s.

Actual and theoretical values are compared on a 36 point per revolution basis for proper angular rate and position to determine gyro accuracy.

IX. Sensitivity Ratio Check:

- A. The gyro sensitivity ratio is determined by positioning the gyro in

servo operation sensing both a plus and a minus one g. and determining the average table angular rate. The average of the two values determines sensitivity ratio which is a criterion for grading the gyro as to quality.

X. Residual Torque Check:

- A. With the gyro in servo position as above and sensing both a plus and a minus g., the T.G. reference winding is excited with a specified amperage and the average table angular rate is determined. One-half the distance in the two values is converted into dyne-cm of torque and designated as Residual Torque.

XI. Command Sensitivity Check:

- A. With the gyro in servo position as above and sensing both a plus and a minus one g., the T.G. is excited with varying amounts of current. Comparison of proportional table rates at each value of excitation current determines a Command Sensitivity.

25 FIG and 25 IRIG-PENDULOUS INTEGRATING and
INERTIAL REFERENCE INTEGRATING GYROS:

- I. Due to the classified nature of testing techniques for the 25 FIG and 25 IRIG units, no discussion of the subject will be held in this booklet. If the reader desires to familiarize himself with the test procedure, he may refer to the following Engineering Specifications.

ES-5427
ES-5428

ES-5429
ES-5430

It is permitted to mention, however, that in respect to gyro quality, approximately the same characteristics are noted in test for the 25 FIG and 25 IRIG units as for each of the rate-integrating and pendulous-integrating models previously discussed.

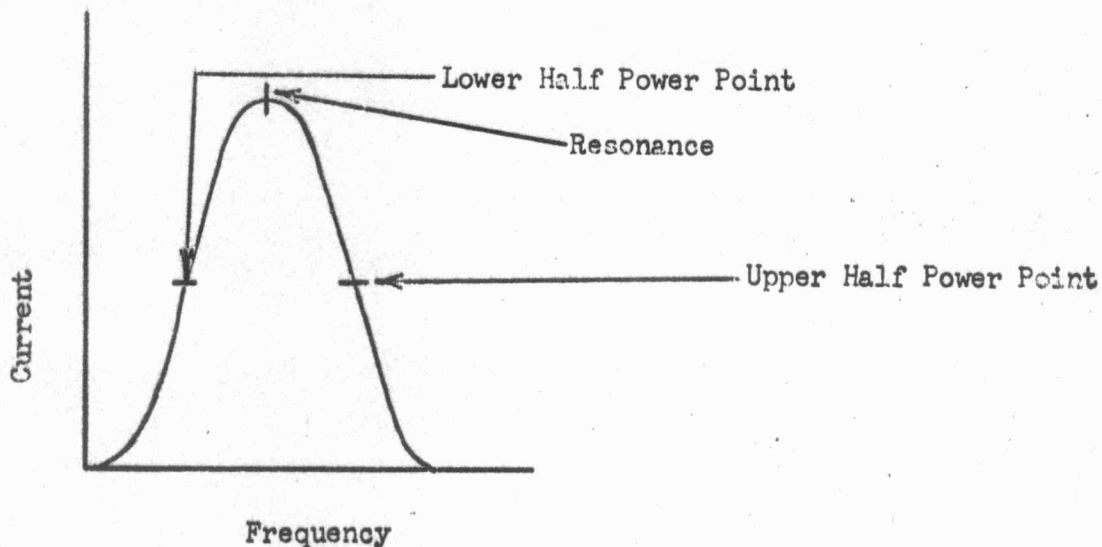
2FBG-2C FLOATED BERYLLIUM GYRO 2.0×10^6

I. Resistance and Continuity Check:

- A. Resistance and continuity checks are done on all the internal circuitry of the gyro. Included in the check is determination of the values of resistance within the heater and sensor windings of the heater jacket to insure that the gyro is subjected to the proper temperature.

II. Half Power Point Determination:

- A. The 2FBG-2C unit utilizes a magnetic suspension system to reduce friction between float pivots and jewel bearings. For the magnetic suspension system to operate properly, it must operate on the proper side of the current-frequency curve and at the right point on the curve. It can be seen from the current-frequency curve below that a half power point exists on both sides of the curve. It is extremely important that operation of the system is performed at the upper half power point. The reason for this is that the inductance characteristics of the microsyn poles reverse themselves between the upper and lower half power points in respect to frequency. If operation occurs at the lower half power point on the curve, reaction of the poles of the microsyn would be such that they would draw the microsyn rotor away from the pivot center instead of toward the pivot center. Since it is possible to operate at either half power point, a check is necessary to insure operation at the proper one.



Since the reference used in the 2FBG-2C unit is 1000 cps, it becomes obvious that the upper half power point must occur at the 1000 cps point on the curve. This is accomplished by adjusting a variable capacitor, called a working capacitor, in the magnetic suspension circuit to obtain the desired operation.

III. Microsyn Polarity Check:

- A. Microsyn polarity is checked by mounting the gyro unit on the turntable with the plus OA vertical and down and exciting the S.G. and T.G. The turntable is rotated both CW and CCW and rotational direction of the S.G. output oscilloscope pattern is observed. This check is performed with no wheel power applied.

IV. Pivot Centering Test and Working Capacitor Adjustment:

- A. With the gyro OA vertical and no wheel power applied, the desired excitation is applied to both the T.G. and S.G. Corresponding pairs of poles of both the T.G. and S.G. are shorted allowing the gyro float pivots to move radially until the pivots are resting against the sides of the jewel bearings. The radial voltage output is noted and recorded

as E_{\max} . This procedure is repeated for the four pairs of poles for the T.G. and S.G. and the radial voltages recorded. When the short is removed from the pole pairs, the float is allowed to come to rest due to the influence of the suspension system and the radial voltage is noted and recorded as E_{rest} . Pivot center radial voltage ($E_{\text{ctr.}}$) is calculated by averaging E_{\max} for each opposing pole pair and the working capacitors are adjusted to produce the calculated $E_{\text{ctr.}}$ value when all microsyn poles are operating normally and the float is at rest in the magnetic suspension system.

V. Float Stop and Float Freedom Check:

- A. With the gyro mounted with plus OA vertical and down and with no wheel power applied, both the T.G. and S.G. are excited. The float is torqued out to the stop in both a plus and minus direction alternately. The S.G. output voltage and the time required for the float to return to a null position are observed. Float operation while being driven to the stops is also observed to insure smooth rotational movement.

VI. Motor Power Consumption Checks:

- A. Motor power requirements to drive the gyro wheel to synchronization are noted. A check is also made on wheel power requirements at given time intervals after the wheel has reached synchronous speed.

VII. Rundown and Preload Test:

- A. Total rundown time from synchronous speed to zero rpm of the wheel is observed. Also, by employing an audio oscillator standard to accurately control wheel power frequency, a rundown time between 600 and 120 rpm's is noted to determine the bearing preload conditions.

VIII. Float Uncertainty Test:

- A. With no wheel power applied, plus OA vertical, down and excitation applied to both the T.G. and S.G., the float is torqued to S.G. output voltage varying from zero to stop values. Reverse torque is applied for each S.G. output to return the float to within 5 mv of the null position. The tumbling loop is engaged and the degree of torquing current necessary to balance the float for each run is recorded. The ability of the torquing loop to return the float to a balanced, or null, condition and the ability of the float to allow itself to be driven to a balanced condition with a given torque applied determines float uncertainty. This method is used primarily to determine if there has been any leakage of damping fluid into the float cavity. A second type of test is given the gyro to determine if there might be any gaseous bubble in the damping fluid. In this check the gyro is allowed to remain at a null with the above excitations applied and the temperature is allowed to vary 3° below normal. It has been found that a temperature variation will cause a bubble in the damping fluid to move its position in respect to the float and will be evidenced by a change in torquing current.

IX. Gravity Transient Check:

- A. With no wheel power applied, plus OA parallel to turntable axis, into the table and horizontal North, and excitation applied to both T.G. and S.G., the gyro is rotated until plus IA is vertical-down. Twenty (20) minutes is allowed for gyro stabilization. Torquing current is applied to the T.G. to null the float. The torquing current is then removed and the tumbling loop is engaged. Torque to balance the float in

terms of dyne-cm is recorded for a twenty (20) minute period. The gyro is rotated thru 360° in 90° increments with the preceeding steps repeated for each 90° position. The change in torque to balance from initial to final values in each orientation will indicate the degree of unbalance present as they are affected by the full gravity vector.

X. Capacitor Package Check:

A. All of the gyro testing done to the present point has been done utilizing the test console working capacitors. At this point it becomes necessary to mount the capacitor package which has been fabricated for the specific gyro under test on the gyro and retest several functions of the gyro while using the fixed capacitors, quadrature resistor and damping resistor in the package. Those tests which must be repeated are listed below:

1. Working Capacitor Values
2. Half-Power Point Check
3. Pivot Centering Test
4. Null Voltage Check

XI. Tumbling Test:

A. With wheel power applied, T.G. and S.G. excitation applied, plus OA parallel to the turntable axis, parallel to EA ± 30 arc seconds and into the table and the gyro operating at flotation temperature, the tumbling loop is engaged. The gyro is positioned with plus IA West for a zero reference. The turntable is driven in a CW direction at twelve (12) times earth rate. Four complete CW revolutions are allowed. The direction of table rotation is then reversed and three CCW revolutions are allowed. Torque to balance in terms of dyne-cm is recorded through-

out both the CW and CCW directions of table rotation. The magnitude of torque to balance is determined at each 10° increment of turntable rotation for the last three CW table rotations and all three CCW table rotations. The resulting data points are reduced by a Fourier Analysis and converted to gyro unbalance coefficients in terms of MERU. Reduction of the data points by Fourier Analysis separates the degree of unbalance as contributed by residual, SRA unbalance, IA unbalance, compliance and indicates the magnitude of each.

XII. Servo Drift Test:

- A. As for the previously discussed units, the servo test is performed to determine the ability of the gyro to maintain an accurate reference. The servo drift test for the 2FEG-2C unit is conducted as follows:

The gyro is mounted to the turntable such that IA is parallel to the turntable axis, plus IA out of the table and perpendicular to the ERA. Plus OA is 45° CCW from the East. One hour of running time is allowed for the gyro wheel to stabilize at synchronous speed.

A compensation current is applied to the T.G. which causes the gyro to drift noticeably in one direction and the gyro is allowed to drift under these conditions for one-quarter ($1/4$) of an hour. The compensation current and total drift are noted and recorded as I_{c1} and D_1 .

Another compensation current is applied which causes the gyro drift rate to decrease or reverse the direction as noted for the first compensation value applied. The gyro is again allowed to drift under these conditions for one-quarter ($1/4$) of an hour. The compensation current applied and the total drift are again noted and recorded as I_{c2} and D_2 .

A compensation ratio is calculated from the information obtained to determine the proper average current necessary to compensate for this residual unbalance, (R-term). This compensation current is applied and the gyro is allowed to drift for one-quarter ($1/4$) of an hour. If the gyro continues to drift beyond specifications, fine adjustments are made in compensation current to obtain zero drift.

Once the proper compensation current has been obtained for zero drift, or drift within specifications, the gyro is realigned to the desired turntable attitude and a two (2) hour drift test is run. Several runs with the gyro mounted in varying attitudes are made to determine final gyro drift qualities.

Assuming that proper compensation current adjustments were made to produce zero drift due to residual unbalances, any turntable movement from the initial position over the two (2) hour period are indicative of gyro inaccuracies due to uncertainty torques and gyro quality. A theoretically perfect gyro free of uncertainty torques would produce no turntable movement during the final drift test.

XIII. Torque Generator Calibration Check:

A. Coarse Control Winding Calibration Check:

1. With the gyro aligned to the turntable with the IA parallel to the turntable rotational axis and perpendicular to the ERA, wheel power and excitation to the T.G. and S.G. are applied. It is extremely important that the specified T.G. primary current is maintained throughout the test. The servo loop is closed and several runs are done with varying values of T.G. secondary excitation. The time required for the float to travel thru a specified angle

is recorded and is used to determine T.G. calibration.

B. Fine Control Winding Calibration Check:

1. Same as for coarse control winding calibration check.

XIV. Flotation Temperature Determination:

- A. The method used here is the same as used for the 1.0×10^7 Mod. II gyro.

XV. Gyro Sensitivity Determination:

- A. The gyro is set up with an initial attitude the same as for the servo drift test. The turntable is rotated until the S.G. output voltage reaches the desired value. At this point the degree of table rotation is noted. The table is then quickly rotated in the opposite direction until a S.G. null is indicated and table position is again noted. The amount of turntable movement required to result in the desired S.G. output and the difference in turntable position as compared to its initial position after returning to a S.G. null is indicative of the gyro sensitivity. Theoretically, a perfect gyro would have caused the turntable to return exactly to its original position when the S.G. null was obtained.

NOTE: Figure 15 illustrates a special device known as a Fluid Package which is used while performing all of the final testing of the 2FBG-2C units. The Fluid Package does not comprise any part of the gyro, but is merely used as a temperature regulating device for the gyro. The 2FBG-2C depends on circulation of heated fluid around it through a ducted Fluid Jacket for the proper temperature conditions.. The Fluid Jacket, not shown, is physically attached to the gyro as an outer case about the main housing and covers over the end housings which allow the heated fluid to pass through them. The Fluid Package acts as an insulator-oven to aid in maintaining proper gyro temperature.

Fluid Lines

IA

Thermistor and Heater
Connector

Microsyn and Wheel Motor
Connectors

Fluid Package

- 82 -

Note: Fluid package is used during testing operations
of 2FEG 2C unit only.

Individual Gyro Characteristics:

I. 1.0×10^7 Model II Rate Integrating Gyro:

A. Construction:

1. Aluminum alloy used in basic structure
2. Cylindrically shaped float.

B. Symbolism:

1. 1.0×10^7 indicates the gyro wheel angular momentum in dyne-cm/rad./sec.

C. Excitation Requirements:

1. Wheel Supply: (12,000 RPM)
 - a. 2 phase, 45 volt, 400 cps.
 - b. 400 ma starting current
2. Torque Generator Excitation:
 - a. 120 ma, 400 cps
3. Signal Generator Excitation:
 - a. 1 volt, 400 cps

D. Hot Gyro:

1. The unit must not be allowed to cool but must be maintained in a heated condition for the life of the gyro after filling.
2. Flotation occurs normally between 160 and 165° F.
3. Utilizes blanket heaters to maintain gyro temperature.

II. 1.0×10^4 Pendulous Integrating Gyro:

A. Construction:

1. Aluminum alloy used in basic structure
2. Cylindrically shaped float

B. Symbolism:

1. 1.0×10^4 indicates the gyro wheel angular momentum in dyne-cm/rad./sec.

C. Excitation Requirements:

1. Wheel Supply: (8,000 RPM)
 - a. 2 phase, 4.25 volts, 400 cps.
2. Torque Generator Excitation:
 - a. 120 ma, 400 cps.
3. Signal Generator Excitation:
 - a. 1 volt, 400 cps.

D. Hot Gyro:

1. The unit must not be allowed to cool but must be maintained in a heated condition for the life of the gyro after filling.
2. Temperature of the unit is adjusted to obtain the desired damping characteristics.

III. 2FBG-2C Rate Integrating Gyro:

A. Construction:

1. Beryllium is used in basic structure.
2. Gyromet material is used for the heavy metal wheel rim.
3. Cylindrically shaped float.

B. Symbolism:

1. First number 2 identifies the unit as possessing an angular momentum of 2.0×10^5 dyne-cm/rad./sec.
2. FBG indicates the unit as a Floated Beryllium Gyro.
3. 2C indicates the unit model number.

C. Excitation Requirements:

1. Wheel Supply: (12,000 RPM)
 - a. 2 phase, 30 volts, 400 cps.
2. Torque Generator Excitation:
 - a. 24 ma, 1000 cps.
3. Signal Generator Excitation:
 - a. 10 volts, 1000 cps.

D. Magnetic Suspension:

1. The unit employs 8 pole microslyn stators combined with 8 working capacitors.

E. Cold Gyro:

1. The unit possesses the ability to be transported and stored at temperatures below the operating flotation temperature of $146 \pm 1^\circ\text{F}$.

IV. 25 PIG Pendulous Integrating Gyro:

A. Construction:

1. Beryllium is used in basic structure
2. Spherically shaped float.

B. Symbolism:

1. Numerals 25 indicate nominal unit diameter in tenths of inches.
2. PIG indicates a Pendulous Integrating Gyro.
3. Unit angular momentum:
 - a. Titan - 3.0×10^4 dyne-cm/rad./sec.
 - b. Polaris - 0.6×10^5 dyne-cm/rad./sec.

C. Excitation Requirements:

1. Wheel Supply:
 - a. Titan - 2 phase, 17 volts, 400 cps.
 - b. Polaris - 2 phase, 28 volts, 800 cps.
2. Torque Generator - Excitation:
 - a. Titan - 10 volts, 1000 cps.
 - b. Polaris - 10 volts, 800 cps.
3. Signal Generator Excitation:
 - a. Titan - 10 volts, 1000 cps.
 - b. Polaris - 10 volts, 800 cps.

D. Magnetic Suspension:

1. Two 4-pole microsins and 8 working capacitors.

E. Cold Gyro:

1. The unit is classified as a gold gyro only when it is shrouded.

V. 25 IRIG Rate Integrating Gyro:

A. Construction:

1. Beryllium is used in basic structure.
2. Spherically shaped float.

B. Symbolism:

1. The numerals 25 indicate nominal unit diameter in tenths of inches.
2. IRIG indicates Inertial Reference Integrating Gyro.
3. 1.4×10^5 dyne-cm/rad./sec.

C. Excitation Requirements:

1. Wheel Supply: (16,000 RPM)
 - a. 2 phase, 28 volts, 800 cps.
2. Torque Generator Excitation:
 - a. 10 V., 24 ma or 3.6 V., 10 ma.
3. Signal Generator Excitation:
 - a. 10 V., 24 ma or 3.6 V., 10 ma.

D. Magnetic Suspension:

1. The unit employs 8 pole micorsyn stators combined with 8 working capacitors.

E. Cold Gyro:

1. The unit is classified as a cold gyro only when it is shrouded.
This enables the unit to be transported and stored at temperatures below the operating flotation temperature of 137° F.

VI. 1.0×10^7 Model VI-A Rate Integrating Gyro:

A. Construction:

1. Aluminum alloy used in basic structure.
2. Cylindrically shaped float.

B. Symbolism:

1. 1.0×10^7 indicates the gyro wheel angular momentum in dyne-cm/rad./sec.
2. VI-A indicates particular gyro model.

C. Excitation Requirements:

1. Wheel Supply:
 - a. 2 phase, 45 volts, 400 cps.
2. Torque Generator Excitation:
 - a. 120 ma, 400 cps.

3. Signal General Excitation:

- a. 125 ma, 400 cps.

D. Cold Gyro:

1. The unit is cycled to a low temperature of $+60^{\circ}$ F. before test and may be considered a cold gyro.

VII. 1.0×10^7 Model VIII Rate Integrating Gyro:

A. Construction:

1. Aluminum alloy used in basic structure.
2. Cylindrically shaped float, lead seals.

B. Symbolism:

1. 1.0×10^7 indicates the gyro wheel angular momentum in dyne-cm/rad./sec.
2. Numeral VIII indicates particular gyro model.

C. Excitation Requirements:

1. Wheel Supply:

- a. 3 phase, 120 volt, square wave.

2. Torque Generator:

- a. D.C. excited, permanent magnet, single winding. Scale factor = 7.5° /hr./ma of torquing current.

3. Signal Generator:

- a. Capacitive pickoff operating on 25 volts, 5 KC.

D. Cold Gyro:

1. The unit operates at a flotation temperature of 125° F. Temperature cycling to $+65^{\circ}$ F. is done after filling and the gyro is classified as cold.

VIII. 3.0×10^7 Mark VII-B Rate Integrating Gyro:

A. Construction:

1. Aluminum alloy is used for the outer housing basic structure and Beryllium is used for the floated unit structure.

2. Cylindrically shaped float.
3. A mechanical type torquer is used in some units.

B. Symbolism:

1. 3.0×10^7 indicates the gyro wheel angular momentum in dyne-cm./rad./sec.
2. MK VII-B indicates the particular unit model.

C. Excitation Requirements:

1. Wheel Supply:

- a. 2 phase, 45 volts, 400 cps.

2. Torque Generator:

- a. D.C. Excited, permanent magnet, single winding when mechanical torquer is not used.

3. Signal Generator Excitation:

- a. 30 ma, 1000 cps.

D. Hot Gyro

1. Heat must be maintained on this unit continuously after filling.
Operating floatation temperature is $145 \pm 1^\circ$ F.

E. Magnetic Suspension:

1. Same as previous units.

V. MICROSYN THEORY

A. Mark VII Microsyn:

1. Magnetic Suspension:

- a. Basically, the Mark VII microsyn has two functions. The first function is to magnetically suspend the float pivots of a gyro in the radial center of the jewel bearings to reduce Coulomb Friction and the second function, depending on whether a signal or torque microsyn is being discussed as on pages 18 and 19, is either to produce a signal which will indicate the rotation and direction of rotation of a gyro float, or to produce a torque which will rotate the float of the gyro in the desired direction. Accordingly, this discussion of the microsyn is divided into three sections. One section deals with torque microsyn and signal microsyn operation.

To become familiar with the principle of magnetic suspension, it is necessary to analyze and understand the simple circuit as shown in Figure 16 and apply our analysis to the Mark VII microsyn.

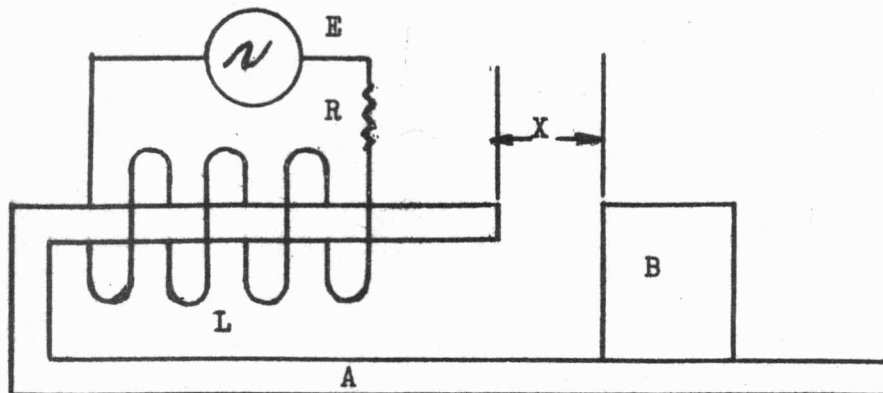


Figure 16

In Figure 16, E represents an AC generator, L is the inductance of the coil wound on the Ferro magnetic A, R is the inherent resistance in the coil windings, and B is a movable block of Ferromagnetic material.

The combination of E, R and L, including associated wiring, will be called the electrical circuit and the combination of A and B will be called the magnetic circuit.

Inductance can be defined as the ratio of the number of flux lines passing thru a coil to the magnitude of the current passing thru the coil. In a magnetic circuit, the flux in the circuit is proportional to the current in the circuit and inversely proportional to the gap between A and B. Thus, the inductance in the electrical circuit turns out to be inversely proportional to the gap spacing and therefore changes as B is moved. Mathematically these statements appear as follows:

$$\phi = \frac{aI}{X} \qquad L = \frac{N\phi}{I} = \frac{NaI}{XI} = \frac{C}{X}$$

Where: ϕ = Flux

a = Constant

I = Current

N = Number of turns
in the coil

L = Inductance

$C = Na = \text{Constant}$

X = Gap Spacing

These formulas are approximately correct in the range where the gap spacing is greater than zero and the ferromagnetic core is not saturated. A graph of L versus X is shown in Figure 17.

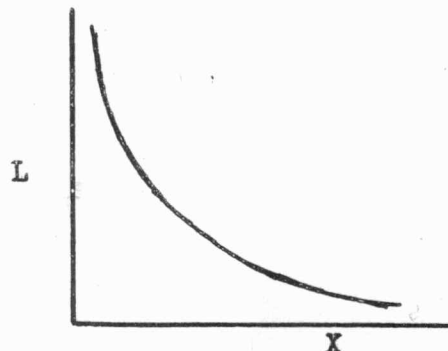


Figure 17

Since the energy in the magnetic field surrounding a coil is given by the formula $W = 1/2 I^2 L$ where W is the energy, I is the current in the circuit, and L is the inductance, it follows that the energy contained in the magnetic field changes as B is moved.

Now let us modify the circuit given in Figure 16 by adding a capacitor C to the electrical circuit as shown in Figure 18.

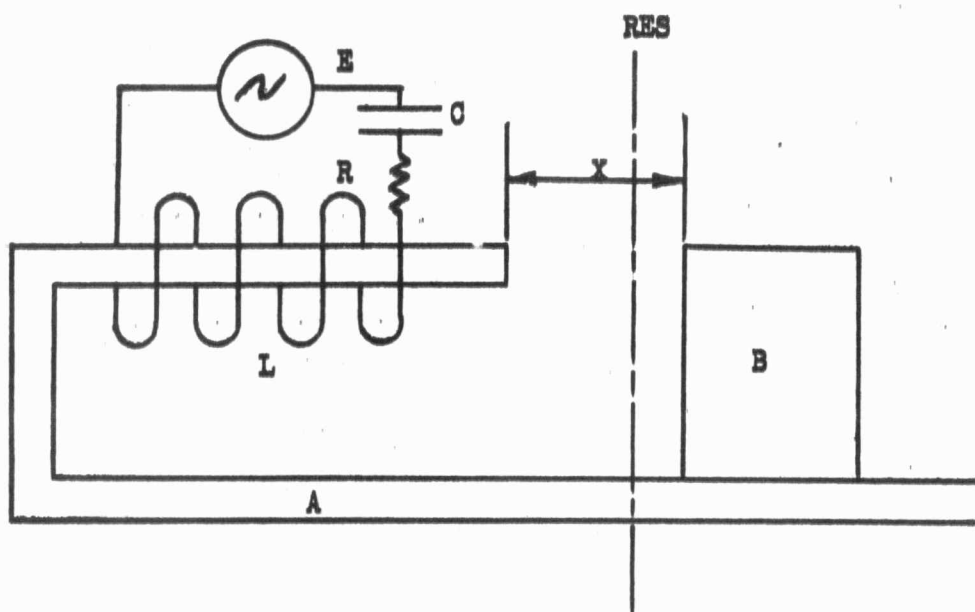


Figure 18

An AC circuit which contains an inductor (L) and a capacitor (C) has the property that for particular values of L and C the circuit will be at resonance. A characteristic of this type of circuit is that at the resonance point the current which flows thru the circuit is at its maximum value. On either side of the resonance point the current decreases rapidly. The rapidity of current decrease is dependant upon the size of the components in the circuit.

The capacitor in the circuit has a fixed value, but the value of the inductor changes as B is moved. Therefore, in Figure 18, if the inductance is originally too small for the electrical circuit to be at resonance, the circuit will approach resonance as B is moved in the X

direction. The point at which resonance occurs is labeled RES. graph of the relationship between I^2 in the electrical circuit and the distance X which B has been moved is shown in Figure 19.

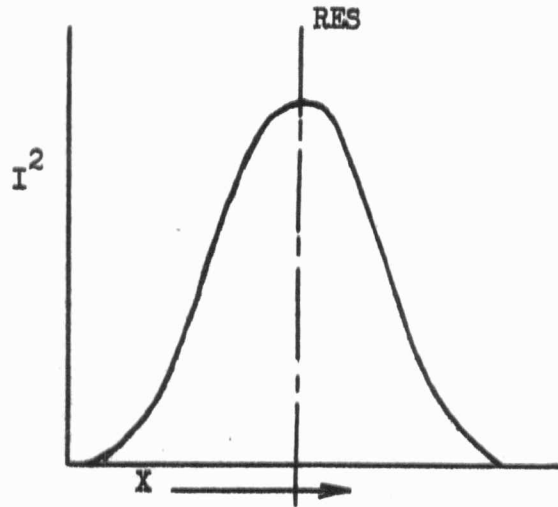


Figure 19

By referring to the equation for the energy stored in the magnetic field of a coil ($W = 1/2 I^2 L$), we can conclude that the graph of the energy stored in the coil field looks similar to Figure 19 except that it is slightly modified by the decrease of inductance with gap spacing.

The relationship between distance and coil energy is very important in the explanation of magnetic suspension. The fact that the coil energy increases as B is moved toward the resonance point indicates that we are moving against a force which is acting on B due to the magnetic field, and that by overcoming this force we are forcing energy into the magnetic field. On the other hand, as the resonance point is passed the energy in the magnetic field decreases indicating that the field is supplying a force which is helping to move B and thereby diminishing the energy contained in the field. The force acting on B at large distances from the resonance point is negligible. Therefore

a general statement about the force acting on B is that it is significant only near the resonance point and is directed in such a manner as to remove the electrical circuit from resonance. A graph of the force (F) versus X is shown in Figure 20.

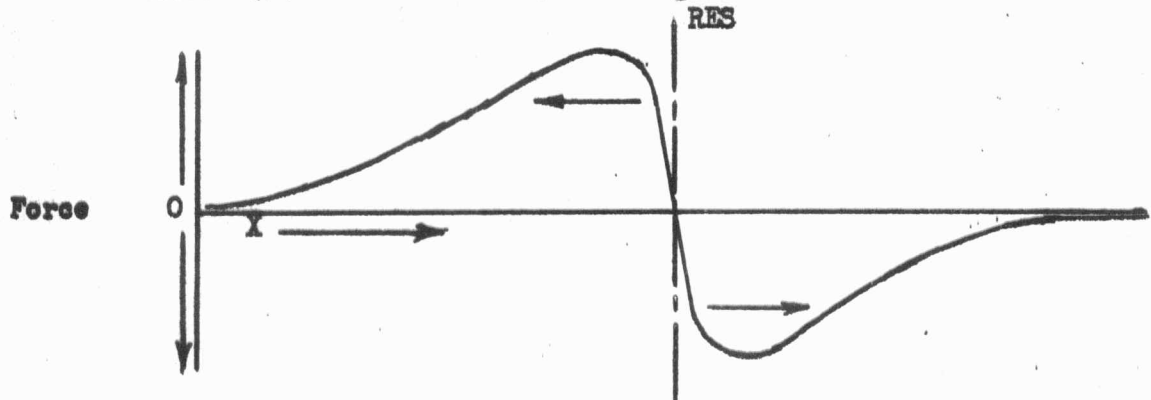


Figure 20

The arrows in Fig. 20 indicate which direction is meant by the two polarities of the force.

Until now, discussion has been limited to the effect of a single resonant circuit upon a block of ferromagnetic material placed in the circuit magnetic field. Let us now direct the discussion toward the effect of several magnetic fields on a block as shown in Figure 21.

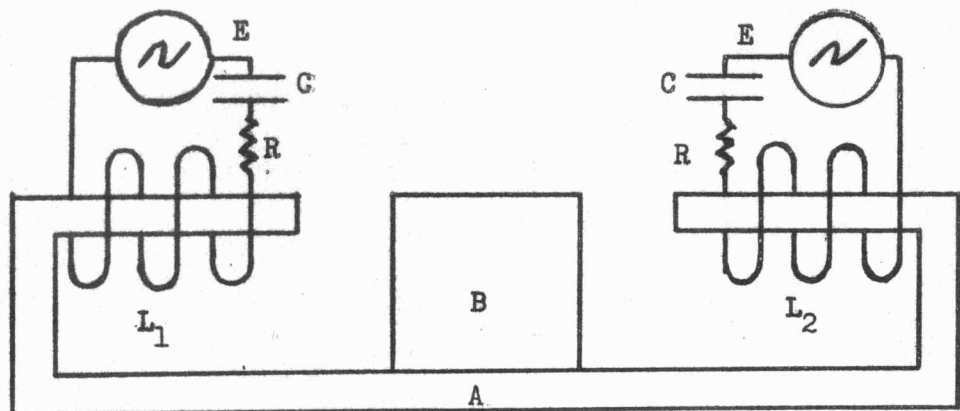


Figure 21

Instead of one force acting on B, there is now a force on both ends of B. On the left end there is a force in the direction of L_1 since

the left end is located in space before the resonance point, and on the right end there is a force in the direction of L_2 . If the two forces are not equal, block B will move in the direction of the stronger force. In order to clearly present what is taking place, let us refer to the force diagram at both ends of B as shown in Figure 22.

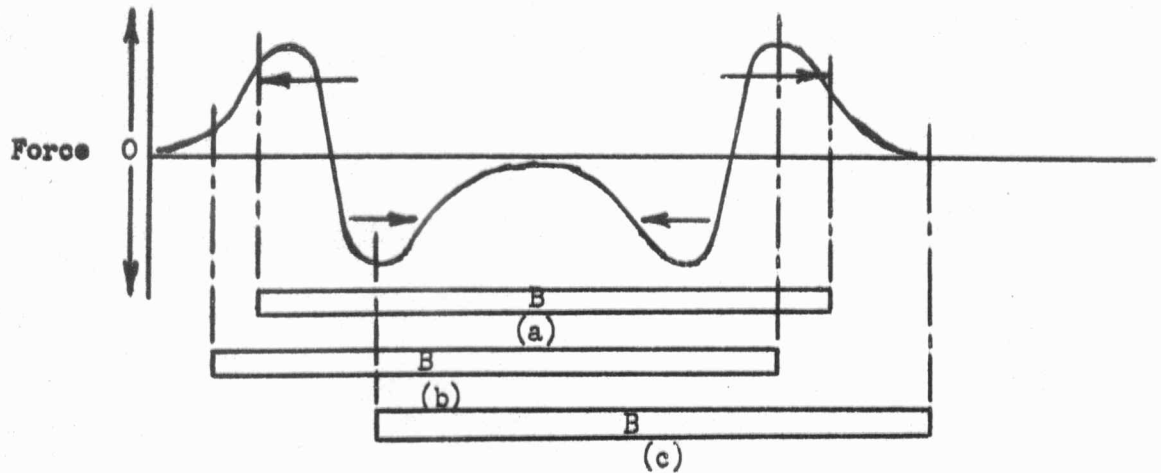


Figure 22

The arrows in Figure 22 indicate the direction of the force and the graph indicates the magnitude. A word of caution must be mentioned before proceeding. The force diagram does not indicate the existence of a field of force in space resembling the diagram. A force of given magnitude exists only when the end face of B is situated at that particular point in space. Thus, the graph in Figure 22 does not mean that different points of B have different forces acting upon them, but only that at the two ends of B there are forces which have the magnitudes as indicated by the graph at these points.

In Figure 22, when B is at position (a) the forces on both ends of the block are equal. Therefore, the block will not move. Now let us assume that due to an external force B is moved to position (b). The

forces on both ends of the block are no longer equal and the block will be forced to move back to its original position due to the influence of the unequal forces. Thus a means has been developed to clamp B at a point between the two resonant magnetic circuits.

If B is acted upon by such a large external force as to force it to position (c) or to any point where one end of B is slightly past the maximum point indicated on the force diagram, the sum of the forces acting on the end faces of the block no longer attempt to move the block back to its original position. For this reason, circuits which utilize magnetic clamping are constructed in such a manner as to make it impossible for the clamped unit to physically move beyond a given desired position. Thus, the unit is magnetically clamped between these physical limits.

A schematic diagram of the Mark VII microsyn is shown in Figure 23. There are eight poles each of which contains two windings. The secondary windings marked S are used either to develop a torque in the microsyn or to develop a signal which is sent to an external circuit to indicate that float rotation has occurred. The primary windings marked P are grouped together in pairs by connecting the primary windings of two poles in series and are used to develop the magnetic suspension forces and also to induce voltages in the secondary. The insert marked B is actually a microsyn rotor which is physically attached to the float end.

The opposing poles of the microsyn act together to clamp B as the previous discussion has indicated, but in this case the poles completely surround B causing a clamping action in all directions and B may be said to be radially suspended.

In the previous discussion very little attention was given to the flux paths in the magnetic material. In the Mark VII, due to the complexity of the circuit and the dual purpose of each primary coil, this must not be ignored. The instantaneous flux paths are indicated by the dotted lines in Figure 23. However, the flux paths in B have been shown only for pole 1.

There are two types of motion that B may possess. Either translational movement along the diameter of the pole face circle, or rotational movement, either CW or CCW, about the float longitudinal axis. It is desired that the rotational movement be indicated by an increase in the number of flux lines through poles 1, 3, 5, and 7, and by a decrease in the number of flux lines through poles 2, 4, 6 and 8. This is what will happen with the poles wound as shown in Figure 23. Note that this is true only because the windings on poles 1 and 5 are wound opposite to the windings on poles 3 and 7. Therefore, the decreases in reluctance to flux lines into B is coupled with a decrease in reluctance to flux lines out of B and the flux increases. If the windings were not wound differently, the decrease of reluctance into B would be coupled to an increase in reluctance out of B and the flux thru all poles would remain constant.

Another point which can now be understood is the necessity for two primary coils being series connected. It is necessary that the magnetic suspension system be sensitive to translational movement and yet if rotational movement of B causes an increase in flux thru a pole, it will change the inductance of the coil which is wound on that pole. By connecting two adjacent poles in series, an increase in the inductance of one is compensated for by a decrease in inductance of the other causing the suspension system to be insensitive to rotational

Mark VII Magnetic Suspension Microsyn

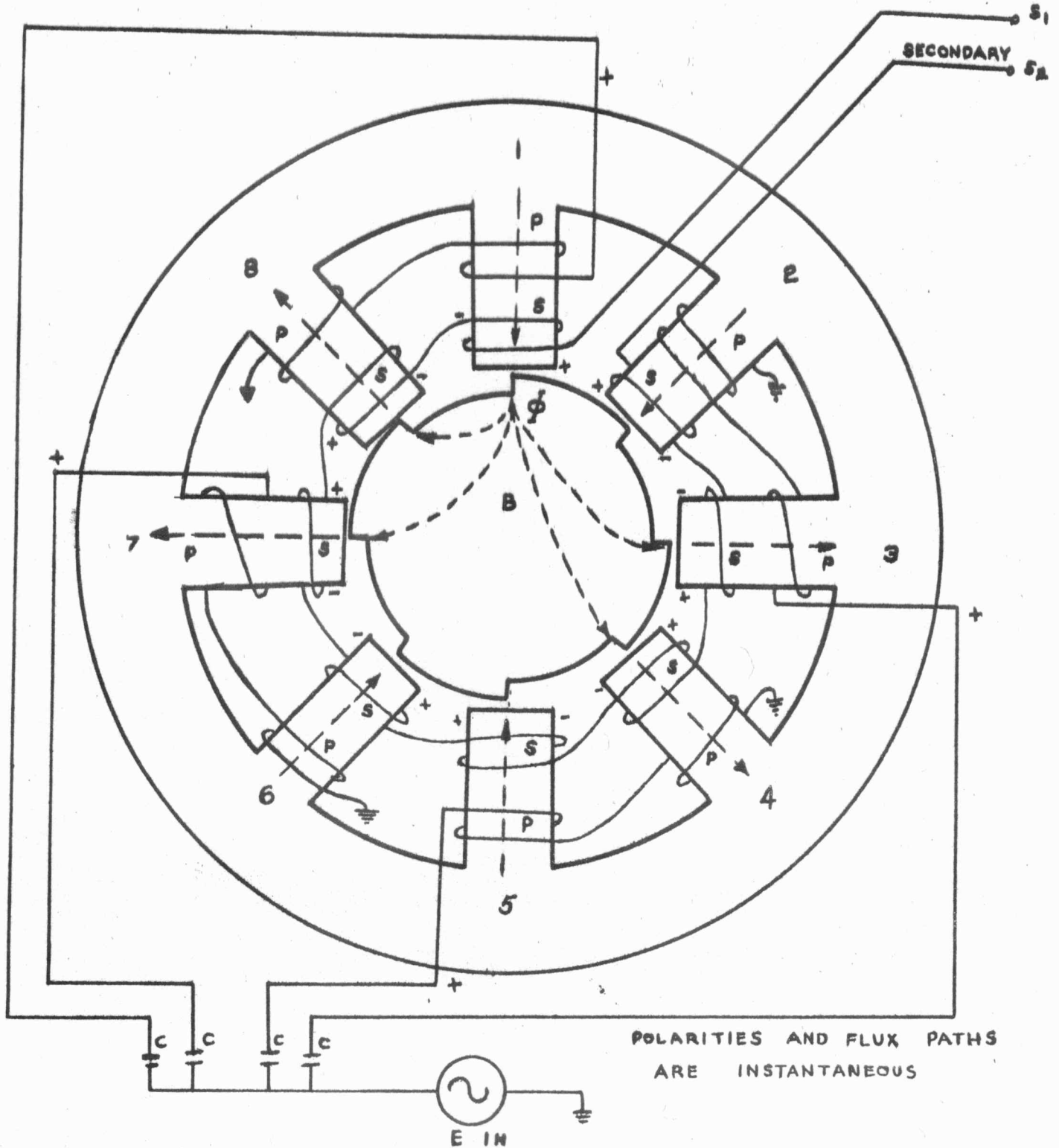


Fig. 23

movement of B,

2. Signal Microsyn:

- a. The signal microsyn function of the circuit is accomplished thru the use of secondary windings half of which are wound so as to produce a voltage in phase and the other half wound so as to produce a voltage which is out of phase with the primary excitation voltage. In Figure 23 the secondaries on poles 1, 3, 5, and 7 are wound in phase and the secondaries on poles 2, 4, 6, and 8 are wound out of phase with their respective primaries. If B is in its neutral (null) position, the flux through all poles is equal and the voltages induced in the secondaries are equal. Since the secondary windings are series connected, the in and out of phase voltages produce an output of zero when algebraically added together. The instantaneous polarities are shown on the diagram. A rotation of B in the CCW direction will cause an increase in the magnitude of the in-phase voltage and a decrease in magnitude of the out-of-phase voltage. The output voltage will therefore be in-phase with the excitation voltage and of a magnitude proportional to the rotational distance traveled by the microsyn rotor. Similarly, a CW rotation will produce an out-of-phase voltage output. Thus, we have a device which indicates direction and magnitude of rotation.

3. Torque Micorsyn:

- a. A torque microsyn differs from a signal micorsyn only in the respect that a voltage is applied to the secondary windings in order to strengthen or diminish the magnetic fields through certain poles and thus create a force which tends to rotate the microsyn rotor. If a signal in phase with the primary voltage is applied to S, in Figure 23, the motion created will be CCW. An out-of-phase voltage on S, will produce a CW rotor movement.

SYSTEMS APPLICATIONS:

	THOR	MACE	TITAN	POLARIS	SINS	ALRI
10 ⁴ (Accel.)	X	X				
10 ⁷ Model II	X	*				
10 ⁷ Model VI-A		X				
10 ⁷ Model VIII					X	
3.0 x 10 ⁷ MK-7-B					X	
2FBG-2C			X			X
25 FIG			X	X		
25 IRIG				X		

*Note: The 10⁷ Model II gyro was used as a Mace gyro earlier in the program but has been superseded by the 10⁷ Model VI-A unit

BIBLIOGRAPHY

"MITAC", The Classroom Gyroscope: AC Spark Plug Division, GMC, Flint, Michigan, July 24, 1958.

An Introduction To The Study of Gyroscopic Instruments: Weems, William R., Cambridge, Massachusetts Institute of Technology.

Engineering Specification Reference

	<u>Test Spec.</u>	<u>Assembly Spec.</u>
1.0 x 10 ⁷ Mod. II	ES-3674 ES-3671	ES-2495
1.0 x 10 ⁴ Mod. II-A	ES-3281 ES-3675 ES-3569	Drawing No's. 8554463, 7919275, 7918760 & 7909175
1.0 x 10 ⁷ Mod. VI-A	ES-5411 ES-5412	ES-3737
25 FIG & 25 IRIG	ES-5427 ES-5428 ES-5429 ES-5430	ES-3224, 3225, 3226, 3227, 3230, 3236, 3237, 3238, 3240, 3241, 3242, 3244, 3245, 3246, 3247, 3256, 3257, 3258, 3260, 3261, 3262, 3263, 3264, 3265, 3266, 3267, 3444, 5544, 5982, 2191, 2229, 2310, 2866
2FEG-2C	XES-6169 XES-6313	XES-6284