INVAR WIRE CALIBRATION AND MEASUREMENT AT THE SYNCHROTRON RADIATION RESEARCH CENTER

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ABSTRACT

The length measurement technique for the storage ring at the Sychroton Radiation Research Center (SRRC) is based on invar wire. To keep the alignment tolerance in the ±0.10 mm range for the magnets along the 120m circumference, the calibration and length measurement accuracy for the invar wire should be in the range of ± 0.03 mm.

Major contributed errors in both calibration and length measurement are identified. To minimize the errors we have implemented certain improvements in the area of instruments, fixtures and baseline.

After we reduce systematic errors through the hardware approach, the computation chart is introduced to compensate to the systematic errors. From network analysis, the result is very consistent in both length and angular measurements.

1. INTRODUCTION

The circumference of most of the dedicated storage rings for synchrotron radiation is in the 20 to 800 meters range. To position the magnetic components, which keep the electrons in their orbit, is the task of the survey and alignment group. This wire technique for the installation of the accelerator components represents the “gaps” between metrological measurements in the laboratory and normal geodetic practice. This intermediate range of measurement from 10 to 1,000 m, could be called macro-metrology or micro-geodesy[1].

New distance measurement systems have been developed, such as the Electronic Distance Measurement EDM[2] and the 3-D Laser Tracking System[3,4]. The invar wire measurement[5] still plays its role in the small accelerators because of economy and ease of operation. The length measurement at the SRRC is based on the invar wire technique, Fig.1.

2. OPERATION AND CALIBRATION

During field measurements we use reference sockets, 30 mm diameter, to define the control points of magnets and survey locations. The invar wire is held by the tension puller distinvar[6] and fixed poster, both are inserted into the reference sockets. The distance between reference sockets is equivalent to the wire length and read-out of the distinvar. The nomial wire length can not be obtained from mechanical devices because the wire is too long to measure. It must be calibrated with a laser interferometer technique.

The invar wire is rather soft and easy to bend during pulling operation and rolling/unrolling procedures. Therefore the nomial length after wire buckling changes from the 0.1 to 1.0 mm. After the wire is used four times or more it needs to be re-calibrated to ensure the actual length.

The use of invar wire (Fig.2) to transfer a standardized length from the metrological laboratory to the accelerator tunnel is in a precision range of 10^{-6}. In order to ensure the measurement quality the invar wire is calibrated by a He-Ne laser interferometer (Fig.3) in the 10^{-7} precision range.

Because the disitinvar measurement can be considered as a sencondary standard, it must be compared to a defined absolute length. Applying the laser interferometer length technique, we can obtain the optical length which corresponds to the associated invar wire length. To combine these two systems into a common place, it requires a baseline(calibration bench) which integrate invar wire(mechanica1) measurement, laser(optica1) measurement and mechanical-optical interface.

The baseline (Fig.4) for the invar wire calibration has five sub-systems:

(1) reference sockets - define the total length for the invar wire and read-out of the distinvar
(2) mirror carriage and slider - transfer the reflector of the laser beam between reference sockets for the related wire length.
(3) optical-mechanical interface - confirms the distance between optical (laser) travelling mirror and reference sockets.
(4) frame - support the sockets, slide and optical-mechanical interface.
(5) sensors - monitoring temperature, humidity and barometric pressure.

The length of the baseline should exceed the length of the longest wire. Because of the limited space the total baseline length in the SRRC is 24 m. Frames are 100 x 100 I-beam which are supported by brackets and attached to the outer wall of the booster ring.

There are three types of linear slide to guide the mirror carriage parallel to the laser beam. Each one has its pros and cons (Table 1). The slide we use in the baseline is a dual linear rail. The individual segments are connected together to make a full length. It is mounted on a 100 x 100 I-beam for support, and carefully aligned for straightness and parallelism.

The reference sockets are mounted on a pair of 100 x 50 U-channels. The reference point of the optical-mechanical interface usually comes in two types: contact or non-contact(Table 2). For simplicity we have chosen the contact-type.

This calibration bench is located along the outer wall of the booster ring, and firmly bolted down to this wall. In this area the temperature is controlled to 20°C± 1°C. Factors of temperature compensation and humidity are therefore negligible.

3. ERROR SOURCE AND TOLERANCE IMPROVEMENT

3.1 Calibration bench

Distinvar, reference socket, mirror carriage and slide, all contribute to the error source in the invar wire calibration. Each procedure must be kept within tight tolerance to ensure that the final length resolution is in the ± 0.03 mm range. The procedure flow chart and specifications are shown in Table 3. However, there are some discrepancies between the ideal and realistic operation. To obtain the specification we must identify the errors and improve the precision.

After several months of work we brought the repeatibilty in the ± 0.03 mm range. Major items in the improvement are: levelling adjustment of the socket, close fitting of the socket and contact pin, rail straightness, parallelism between the laser and slide, straightness and levelling of mirror carriage and the stability of the socket support. Each item is pushed to the mechanical limit of ±0.01mm. The over-all errors including tension, clearance and optical-mechanical interface are controlled in the ± 0.03 mm range. Detailed efforts are summarized in Table 4.

3.2 Field Operation

During field operation the major contributed error is the clearance between the reference socket and the inserted components. We use the reference socket to represent both the fiducial point of the magnets and the survey position of the wall bracket and pillar. After leverage effect in the fixed poster the error is enlarged to 0.15 mm under the 15 kg tension force. The least sqaure fitting adjustment value was 0.30 mm in the network analysis including length, angular and offset measurement. Our data shows some discrepancy between length and angular measurement.

To improve the measurement we made the following adjustments:
(1) New and tight clearance sockets are installed to replace loose ones. However, wear-out of the center hole and elastic deformation under tension has to be taken into account.
(2) All local force centering offset values due to the tension force are recorded, then the length data are compensated with offset values(Table 5). From the network analysis, overall adjustment error is within 0.10 mm range which shows good compability between length and angular measurement.

In order to ensure the quality of the length measurement, the offset values in forced centering sockets must be verified everytime a network survey is needed.

4. DISCUSSION

4.1 Notes on the Calibration Bench

The linear bearing slide is acceptable in the 10^{-6} range in terms of economy. If higher precision in the 10^{-7} range is needed for the primary baseline such as, for example, at the European Synchrotron Radiation Facility (ESRF), the use of air bearings is mandatory and environmental control needs tight specifications. However, this makes the set-up cost extremely high.

4.2 Forced Centering Socket

For the repeated measurements all the reference points must be forced centering sockets to reduce set-up errors and time. The simplified CERN type socket combines two functions: the center hole fit for the inserting post to guarantee the concentricity and the upper cone to confine the center of the Talyor-Hobson sphere(Fig.5).

Two important factors must be taken into consideration:
(1) Repeatability and stability - To ensure the position is not influenced by external forces and environmental variations.
(2) Clearance between matching components - The instrument or signal receiver adaptor is attached to the socket via a centering hole or cone. If the clearance is too tight (g5/H6), it might be hard to disengage or may be frozen by external debris. On the other hand, if the clearance is too loose (g6/H7 or g7/H8), the concentricity is not good enough ($\geq$ 0.015 mm) and the offset is out of specification.

Using a hydraulic expansion mandrel(Fig.6) is a quick solution to overcome clearance problem. However, there is no thru hole in the center which limits the fixture adaptor conversion. The alternative solution is a socket with precision fitting and smooth surface to overcome this problem. When the socket is made out of aluminum the surface hardness can be improved by hard anodizing (0.015 mm thickness) or electrolyzing nickel plating (0.02 mm thickness). The surface roughness should be specified as less than 1.5 μm. Except the offset due to the pulling force the position error is less than the sum of the clearances between the matching parts.

5. CONCULSION

This application is suitable for length measurement in the short range of 10 - 50 m and a resolution of ± 0.01 mm. With error compensation the accuracy of the invar wire measurement can be kept in the ± 0.03 mm range. However, the measurement slope is limited to the 11% range due to distinvar constrains. The basic network of invar measurements is 2-D and can be extended to 3-D with associated leveling measurements. Small accelerators and large construction works can apply invar wire techniques for space coordination and linear deformation.

Although the 3-D laser tracking system has simple, rapid and automatic measuring capabilities, the retro-reflector must be moved by manual or automatic operation. Therefore, the primary application of the 3-D laser tracking system is in robot calibration. In the long run, invar wire measurement in the accelerator survey task will be replaced by the 3-D laser tracking system provided the retro-reflector movement can be simplified and the set-up cost made competitive.

ACKNOWLEDGEMENTS

I am indebted to Mr. Shi-Jou Ho for his numerous efforts to solve and improve the calibration bench performance. Mr. Chien-Kuang Kuan and Tzu-Ying Cheng and all the members involved in the invar wire measurement are herewith acknowledged.

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[2] T. Copeland-Davis, Proc. 1st Int. workshop on Accelerator Alignment, SLAC, Stanford, CA., USA, 1989.

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Table 1 Slider System Comparison

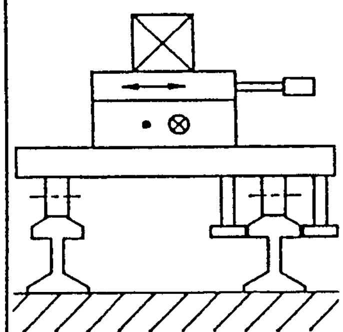
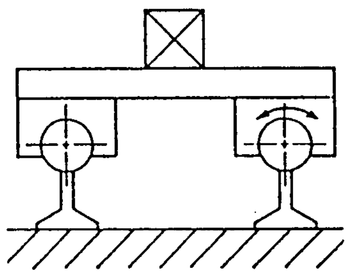
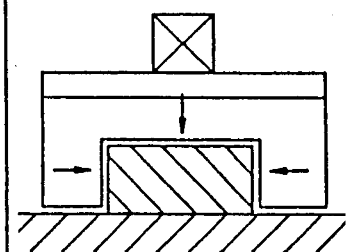
Moving System	Rail Slider	Linear Bearing	Air Bearing
Design Principle	Carriage guide by rail, then locked and fine adjusted.	One rail control direction and the other rail support weight and the levelling	Lapped granite define straightness and keep clearance
Drawing			
Operation	Complicated. After reach set point align to the laser beam via optical aligner	Simple, manual operation.	Easy, Automatic motion incorporated with stepping motor
Straightness Error/meter	≤ 500 μm	≤ 50 μm	≤ 10 μm
Cost ($/meter)	500 - 1,000	1,500-3,000	5,000
Used at	CERN, BNL	SLAC, SRRC	ESRF

TABLE 2 OPTICAL-MECHANICAL INTERFACE

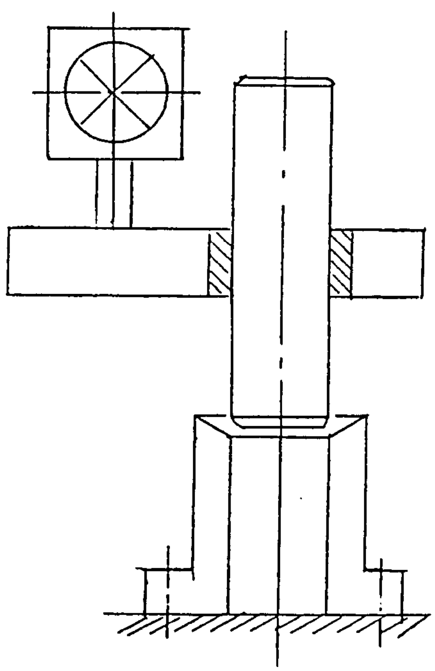
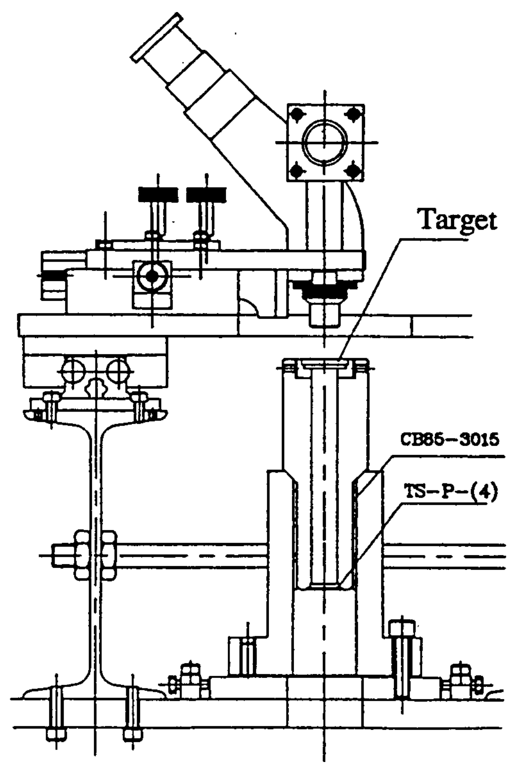
Type	Contact	Non-contact
Design	Set refelector's position to the reference socket by contact pin.	Align the center of mirror and the center of object in the microscope via optical method
Operation	Simple	Foucus adjustment and reading error
Error Source	Clearance between the transfer pin and the reference socket ± 10 - 20 μm	1. Alignment errors 20 - 50 μm 2. Cosine error due to verticalization.
Drawing		
Used at	SLAC, SRRC	CERN, BNL, KEK

TABLE 3 Invar Wire Calibration Procedure and Specfication

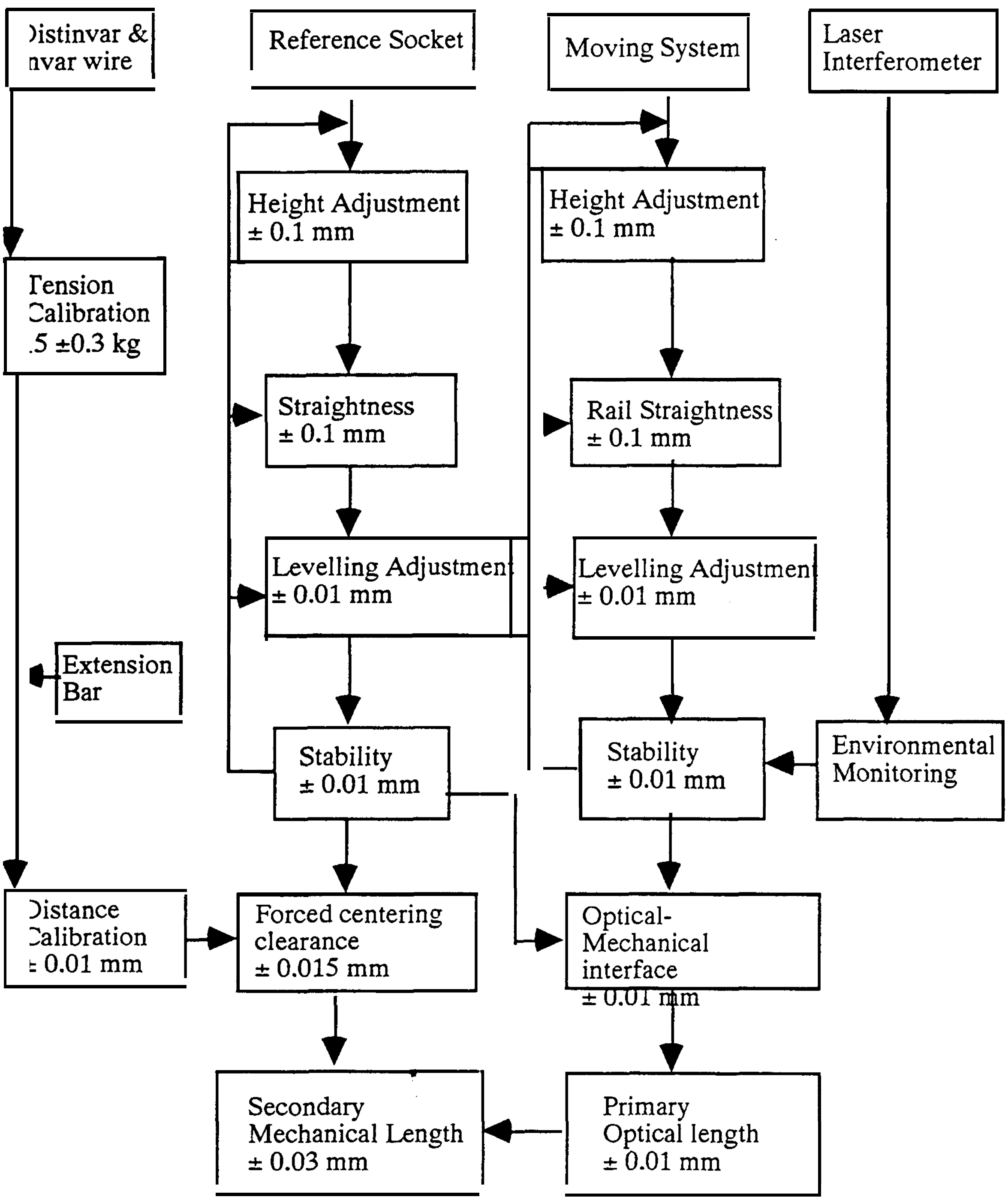


TABLE 4 Error Sources and Improvement in Bench

Item	Error (mm)	Improvement	Error (mm)
1.Forced centering clearance Matching components: transfer pin and socket	+ .041 +. 007	Fitting change from g6/H7 to precision fitting g5/H6	+ .029 + .007
2. Socket support bracket elastic deformation due to 15 kg pulling force	± .01	Reverse socket position upside down. Continueous socket support bracket	± .002
3. Clearance between rail and slider bearing	± .02 @ 400	Adjusted clearance, change roller type slider, and extend carriage span from 200 to 400.	± .01 @ 200
4. Pitch between miror carriage and the laser source	±.05 @ 140	Shift trace of mirror carriage above the top of the reference sockets	±.02 @ 150
5. Roll and yaw between mirror carriage and the laser source	± 2 @20 m	Combine the efforts of item 3 & 4, and the height of the sockets. Average reflect intensity increasing from 35% to 70%.	± 1 @ 20 m
6. Tension test in the distinvar	± .01	a. System error: # 917 vs # 918 b. Travelling error: the digital read-out in milling machine vs disitnvar	± .01
7. Extension bar calibration (40, 60, 80, 100, and 160 mm)	± .03	Calibrate the actual length of the extension bar with the distinvar	± .01
8. Average mechanical errors (1- 4)	± .04	Average mechanical errors (1- 4)	± .02
9. Total errors (1-7)and repeatbility	± .07	Verify the invar wire with different sockets station	± .03

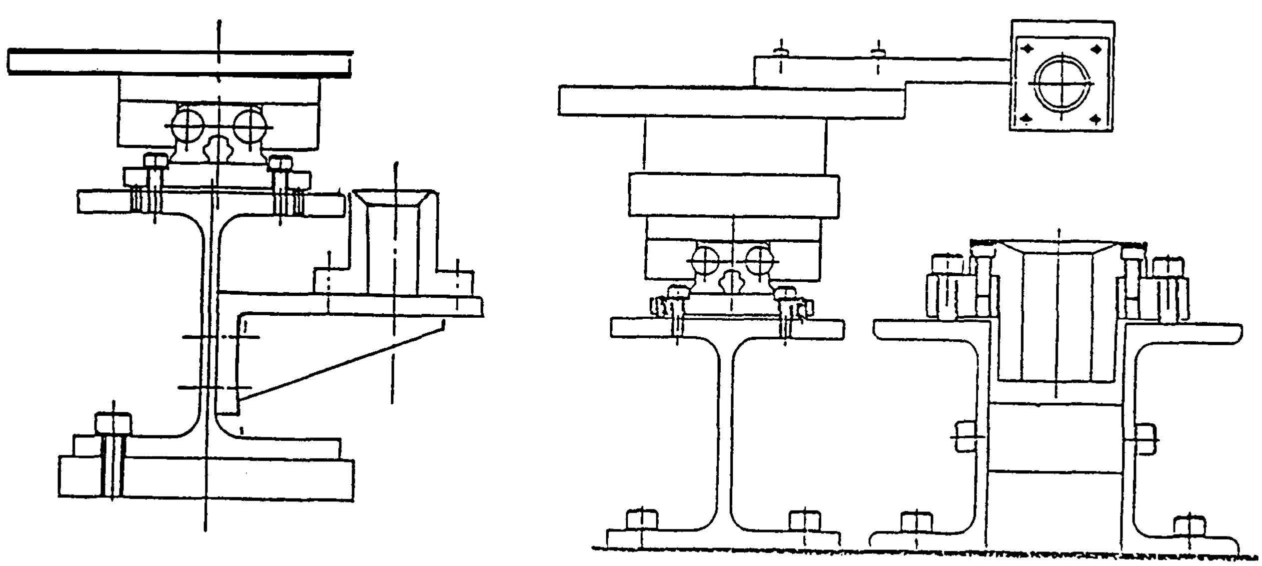
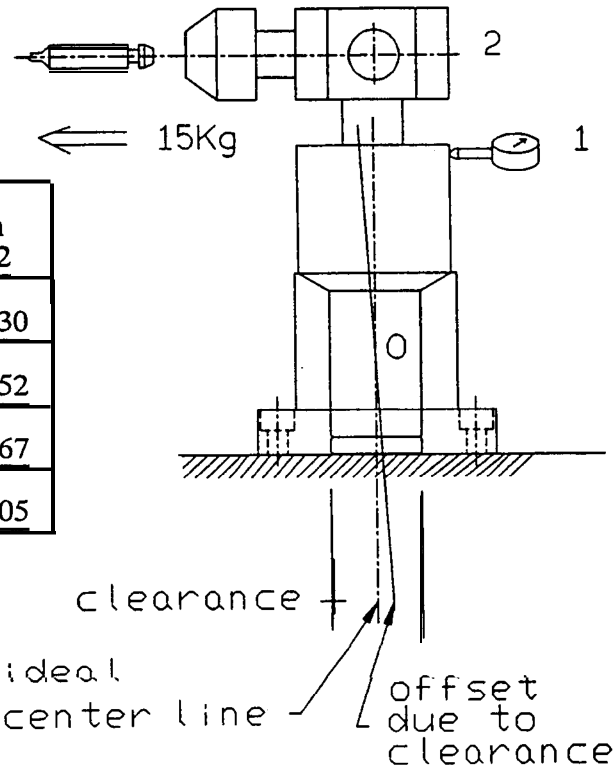


TABLE 5 OFFSET VALUE IN FORCED CENTERING SOCKET DUE TO TENSION



$O1 = 30 + 40 = 70$
$O2 = 30 + 40 + 35 = 105$

$O2/O1 = 105/70 = 1.5$

Type A

I. Offset Value in Different Position

Item	Type	Clear-ance	Position 1	Position 2
a. Calibration Bench	A	.020	.020	.030
b. Storage Ring Center	B	.030	.035	.052
c. Bending magnet (BM)	B	.040	.045	.067
d. Wall Bracket (WB)*	A	.040	.070	.105

* Clearance & elastic deformation

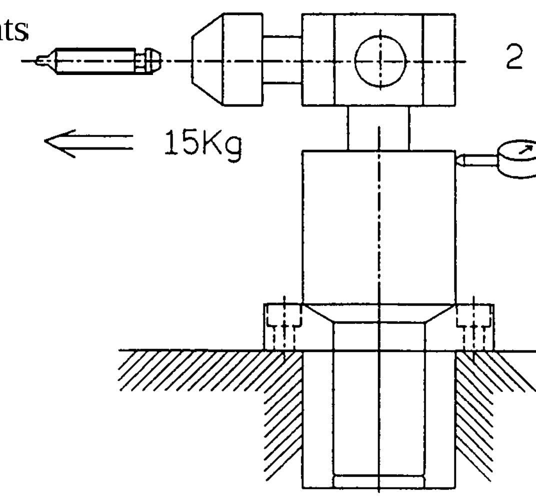
II. Compensation Data in Position 2

Item	The offset difference between the sockets and bench
a. SC	052 - .030 = .023
b. BM	.067 - .030 = .037
c. WB	.105 - .030 = .075

III. Compensation Data for the Dual Points

Starting- Ending Pt.

a. SC - BM	.023 + .037 = .060
b. SC - WB	.023 + .075 = .098
c. BM - WB	.037 + .075 = .112
d. WB - WB	.075 + .075 = .150
e. BM - BM	.037 + .037 = .074



Type B

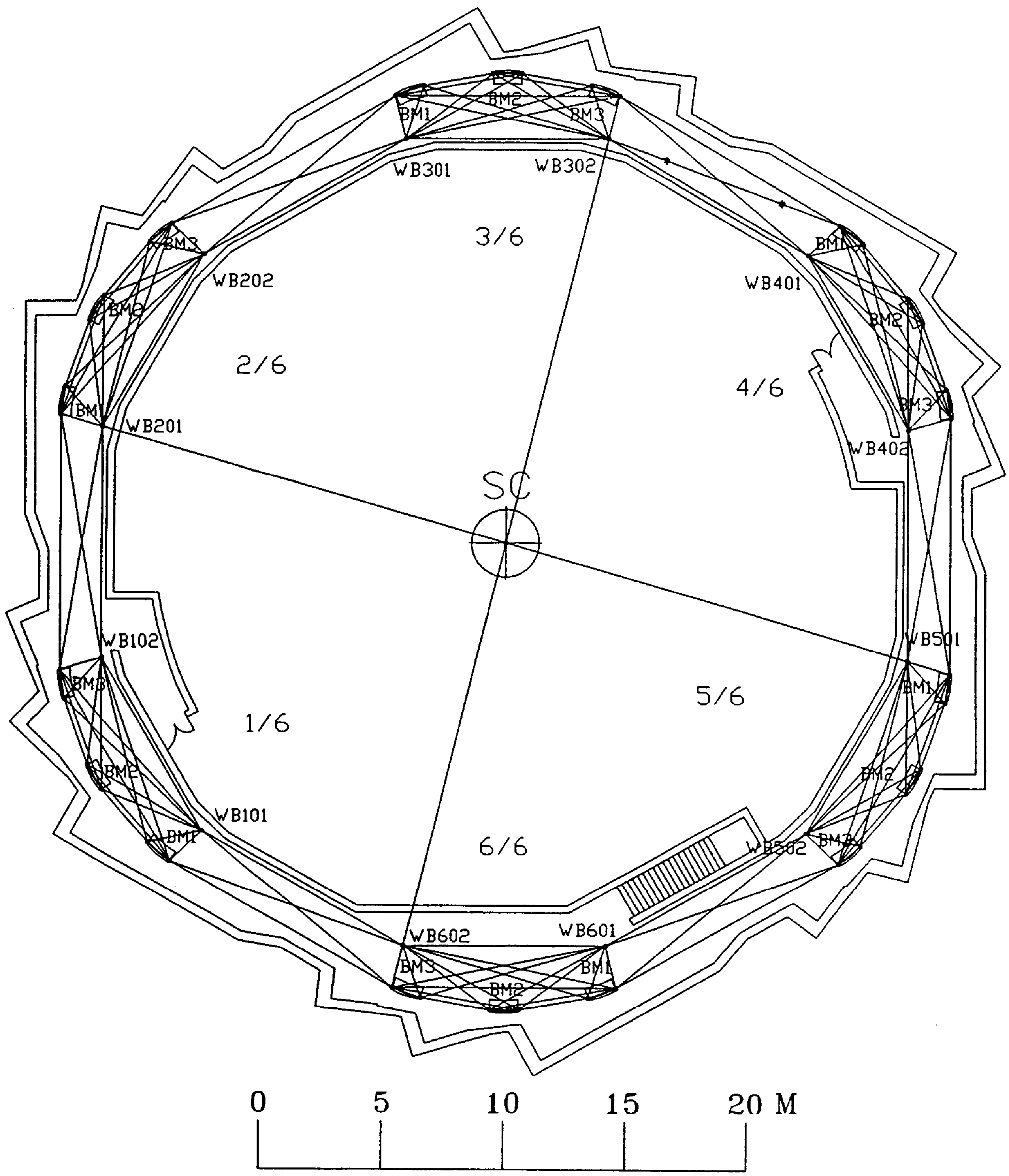


Fig.1 The Survey Network in the Storage Ring

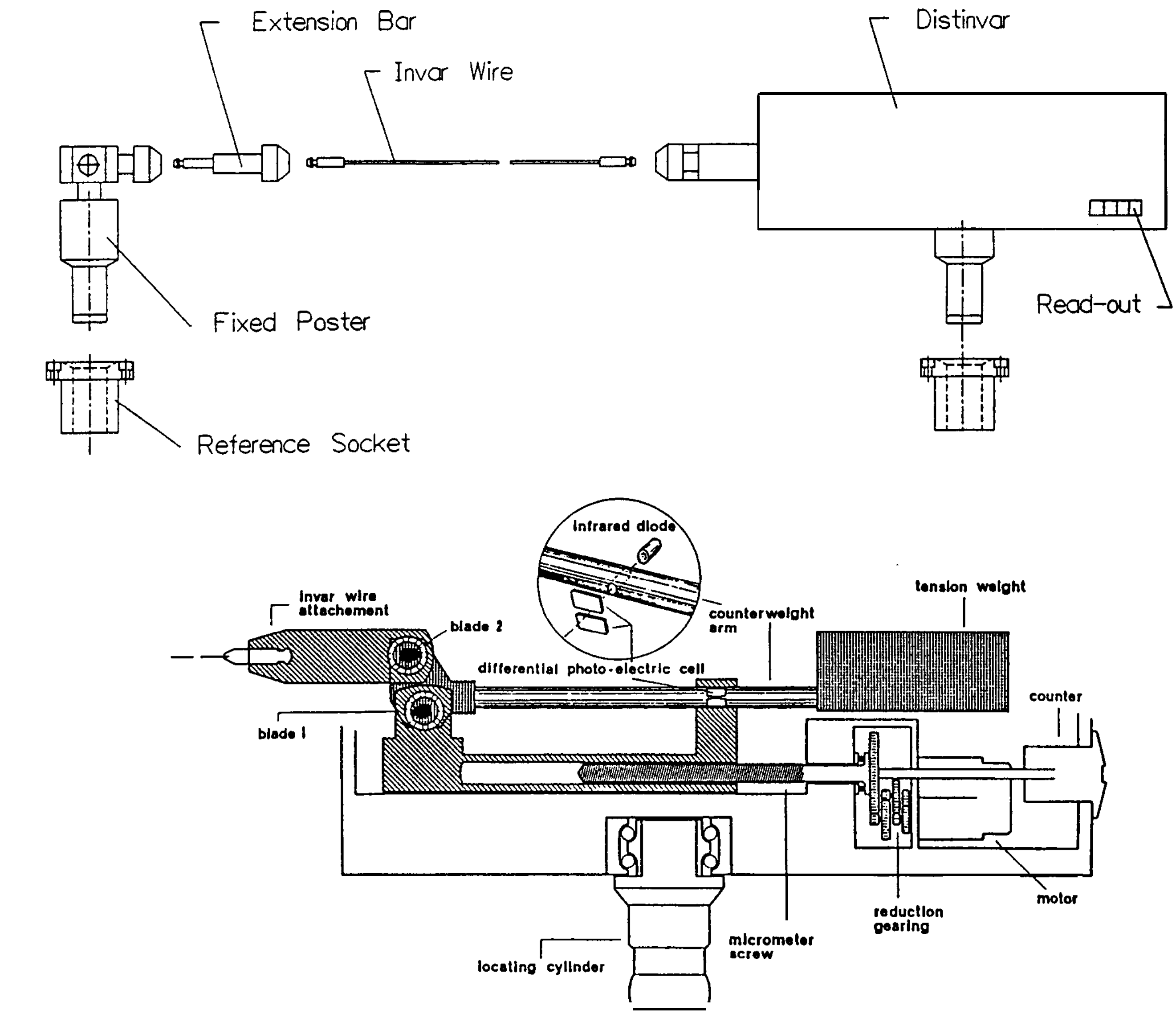


Fig.2 Distinvar and Invar Wire

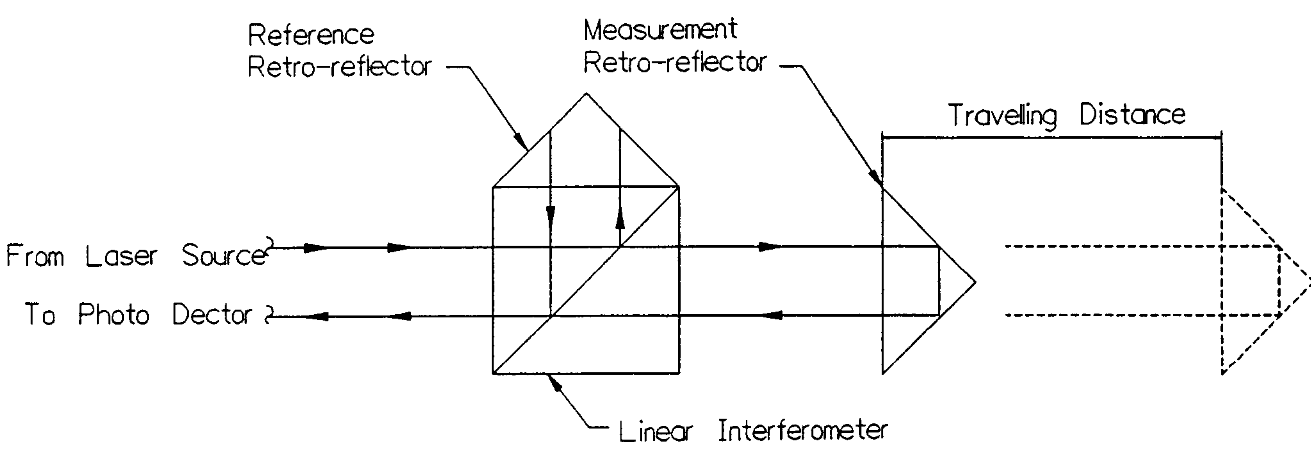


Fig.3 Distince Measurement in Interferometer

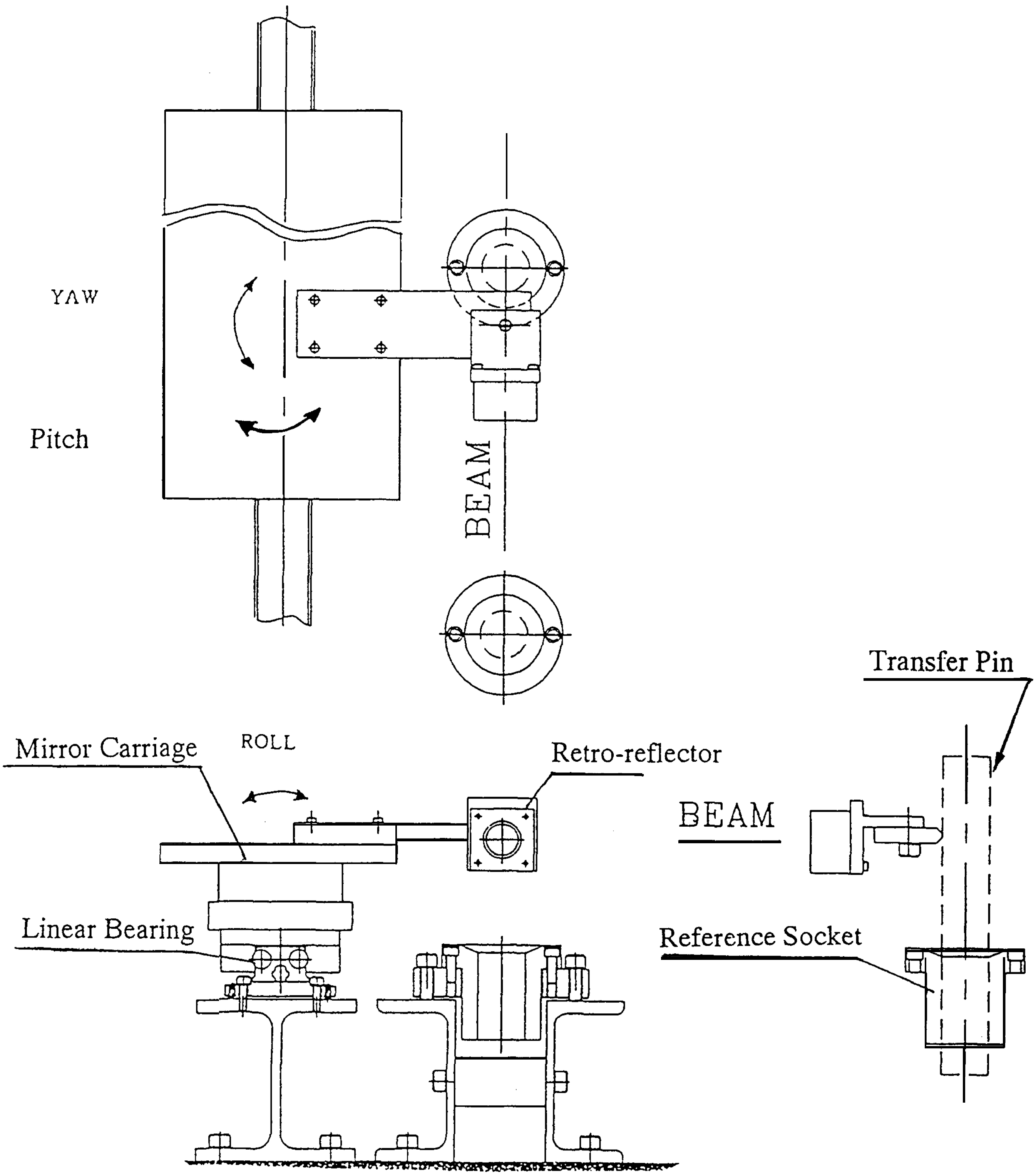


Fig. 4 Invar Wire Calibration Bench

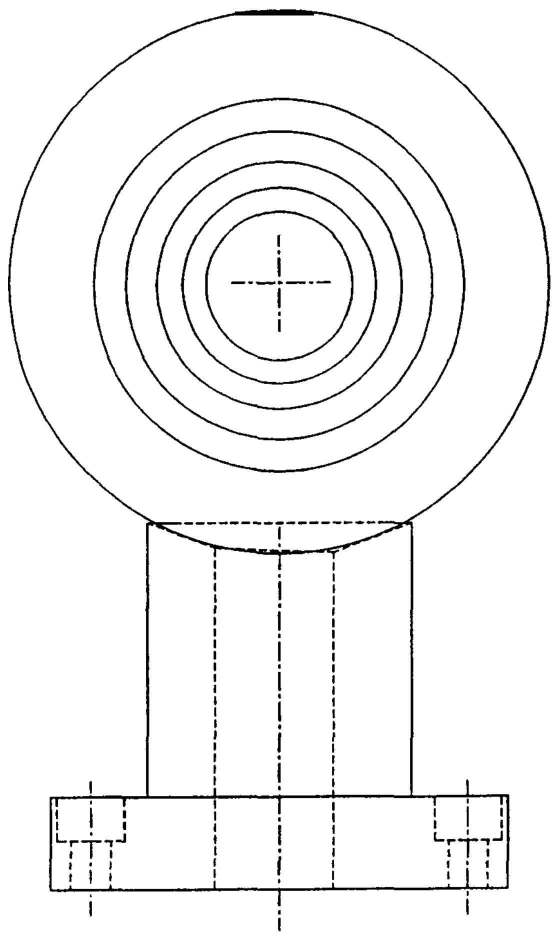


Fig.5 Talyor-Hobson Ball and Forced Centering Socket

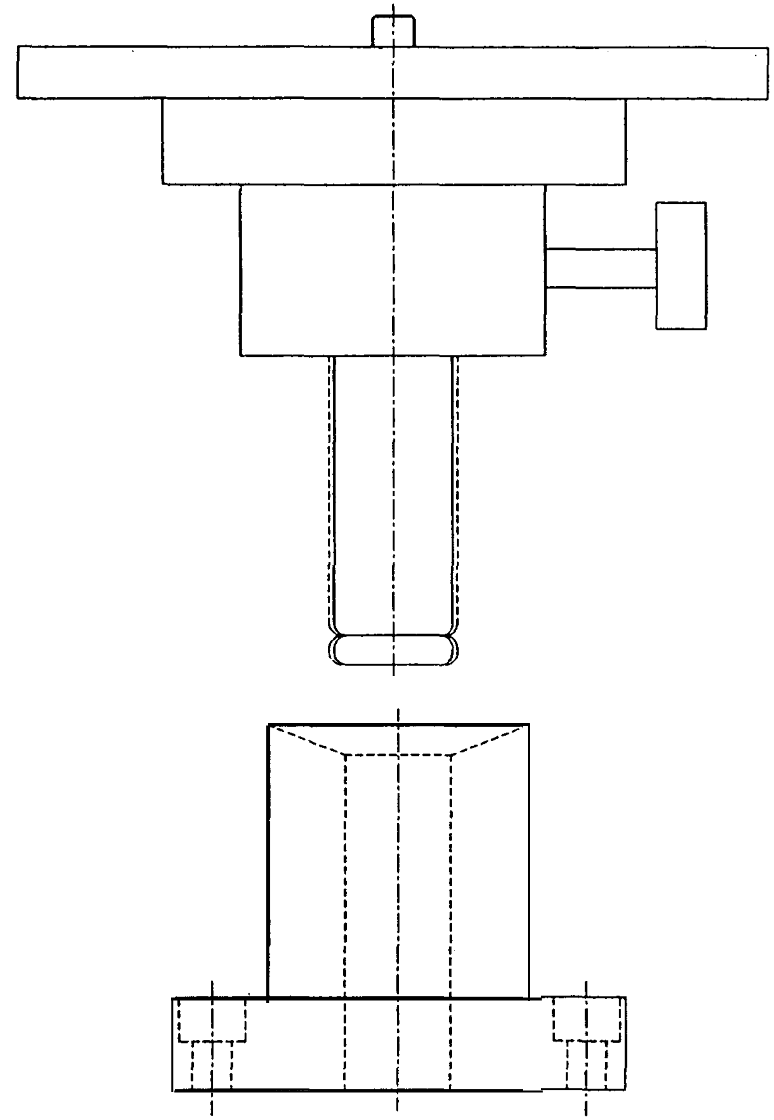


Fig.6 Hydraulic Expansion Mandrel and Forced Centering Socket