THE PRECISION SELF-METERING STRUCTURE (PSMS)

BY

W.C. YAGER

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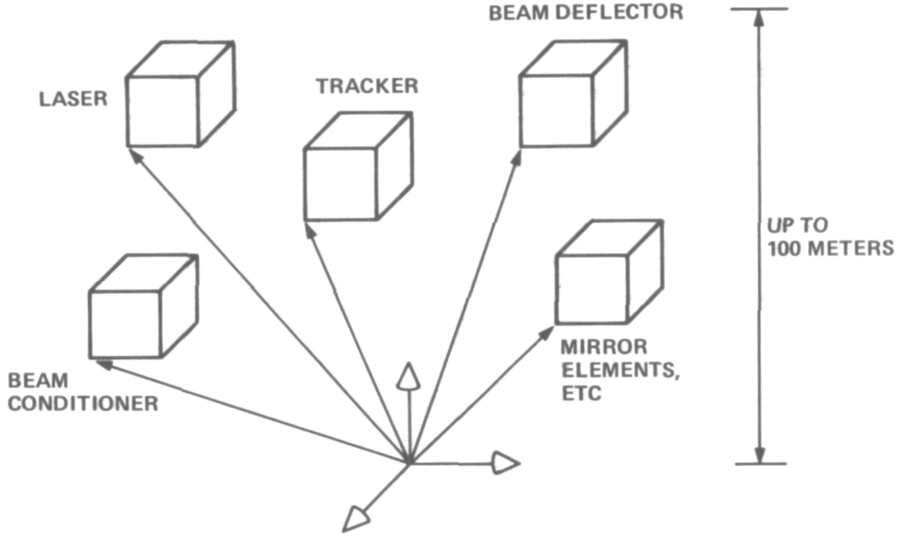
1021

ORIGIN AND SCOPE OF THE PROBLEM (Figure 1)

Large, precise space systems such as space lasers, space telescopes, and space power transmitters cannot be realized until certain fundamental metrological problems are first solved. It must be shown (1) how a spatially distributed system of elements can be tied together in terms of a master coordinate system, (2) how master coordinates for these distributed elements can be determined with great accuracy, and (3) how mechanical integration of the elements to desired master coordinates of such accuracy can be achieved.

ORIGIN AND SCOPE OF THE PROBLEM



FUNCTION REQUIRES GEOMETRICAL INTEGRATION TO 10^{-6}m, 10^{-7} rad
BUT
SYSTEM ELEMENTS ARE PHYSICALLY SEPARATED BY UP TO 100 m

METROLOGY	COORDINATE INTEGRATION	PUT SPATIALLY DISPERSED SYSTEM OF ELEMENTS ON MASTER COORDINATE SYSTEM
	COORDINATE DETERMINATION	DETERMINE MASTER COORDINATES OF ELEMENTS IN REAL TIME TO 10^{-6} m, 10^{-7} rad
STRUCTURE & CONTROLS	MECHANICAL INTEGRATION	ACHIEVE AND MAINTAIN DESIGN MASTER COORDINATES TO 10^{-6}m, 10^{-7} rad

Figure 1

MORPHOLOGY OF METRICAL STRUCTURES (Figure 2)

Three fundamental operations are available to the metrology designer: spacing, alignment, and collimation. Assuming at least one spacing operation is always necessary to establish scale, four general types of metrology systems are possible. The PSMS metrology system is based on the use of spacing operations only.

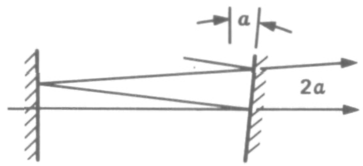
MORPHOLOGY OF METRICAL STRUCTURES

BASIC METRICAL OPERATIONS

1. SPACING

2. ALIGNMENT

3. COLLIMATION



TYPES OF METRICAL SYSTEMS

TYPE 1: SPACING ONLY

TYPE 2: SPACING AND ALIGNMENT

TYPE 3: SPACING AND COLLIMATION

TAPE 4: SPACING AND ALIGNMENT AND COLLIMATION

THE PSMS SYSTEM

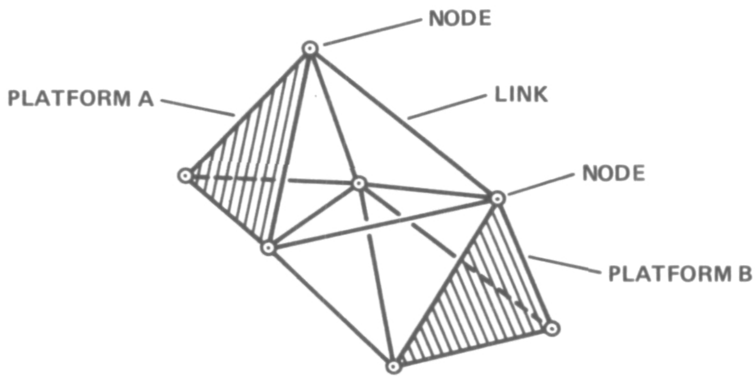
A TYPE 1 SYSTEM

Figure 2

A SPACER-ONLY INTEGRATION CONCEPT (Figure 3)

Spacer-only integration can be realized in a spaceframe of the ball-strut type. In the PSMS system, the load-bearing and dimensional control functions are each assigned to a separate ball-strut spaceframe; these two structures are then arranged to occupy the same space, that is, they are made coaxial. Load-bearing is handled by a hollow, ball-strut exostructure. Dimensional control is handled by a metrical endostructure.

A SPACER-ONLY INTEGRATION CONCEPT



CONCEPT

1. DEFINE PLATFORMS IN TERMS OF NODES
2. INTERPOSE CONNECTING NODES AND LINKS
3. CONTINUOUSLY DETERMINE LENGTHS OF ALL LINKS
4. FROM LINK LENGTHS COMPUTE NODE COORDINATES
5. ADJUST NODES TO ACHIEVE DESIRED COORDINATES

IMPLEMENTATION

1. BASIC DESIGN: BALL-STRUT SPACEFRAME
2. LOAD-BEARING FUNCTION: EXOSTRUCTURE
3. DIMENSIONAL CONTROL FUNCTION: ENDOSTRUCTURE

Figure 3

LOAD-BEARING EXOSTRUCTURE (Figure 4)

The load-bearing exostructure will have the general form of hollow balls at the nodes, with hollow struts connecting the nodes. Many mechanical design variations are possible, but, in general, a telescoping feature and a spherical seating feature should be included among the strut details to facilitate erection.

LOAD-BEARING EXOSTRUCTURE

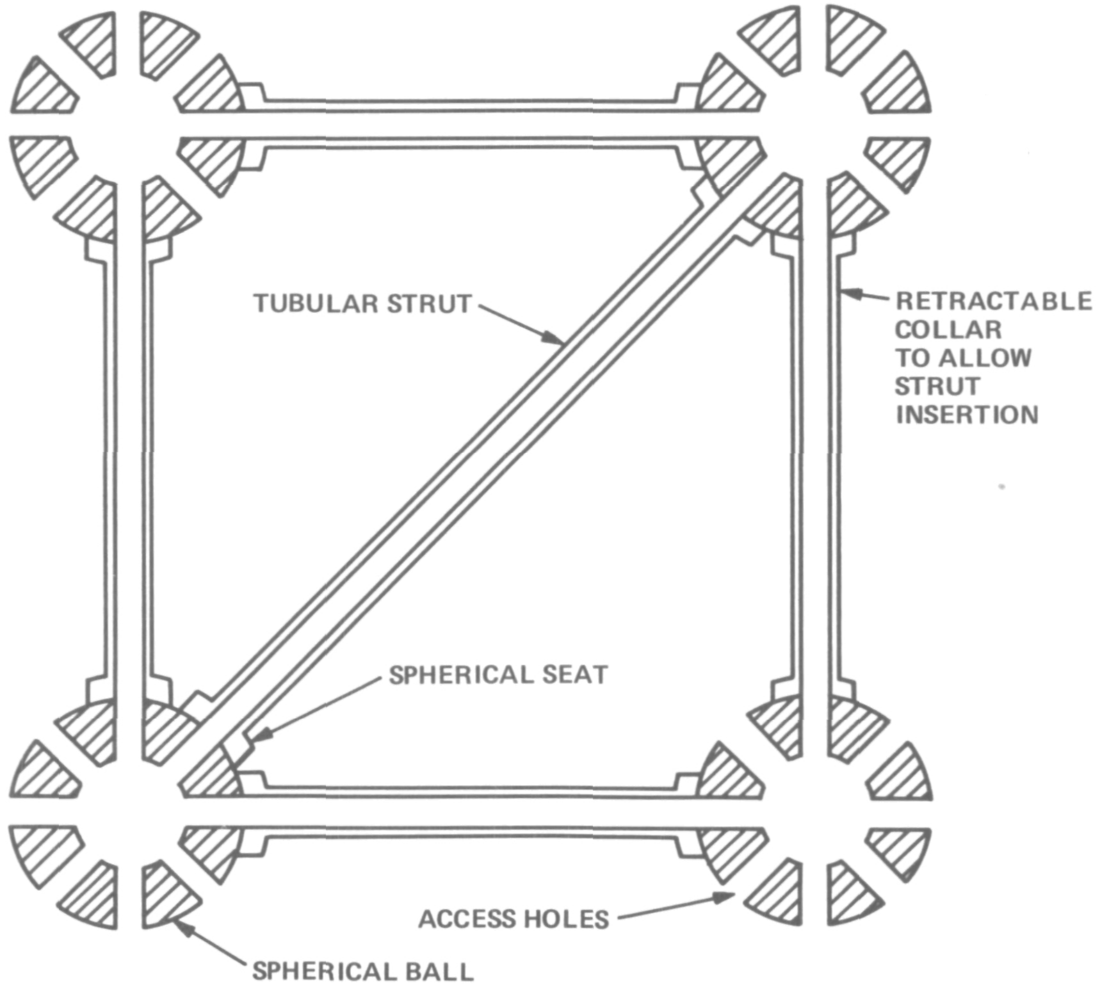


Figure 4

METRICAL ENDOSTRUCTURE (Figure 5)

The metrical endostructure will include (1) precision balls, whose surface centroids define the nodes, and (2) spring-loaded quartz spacer assemblies that bear against the nodal balls and complete the physical internodal link. A gas spring is preferred because it eliminates the need to calibrate for contact force. The spacer assembly will include at least two members (as a rod free to slide within a tube) arranged to allow a telescoping action. An absolute displacement gauge will indicate the relative movement of the two quartz spacers.

METRICAL ENDOSTRUCTURE

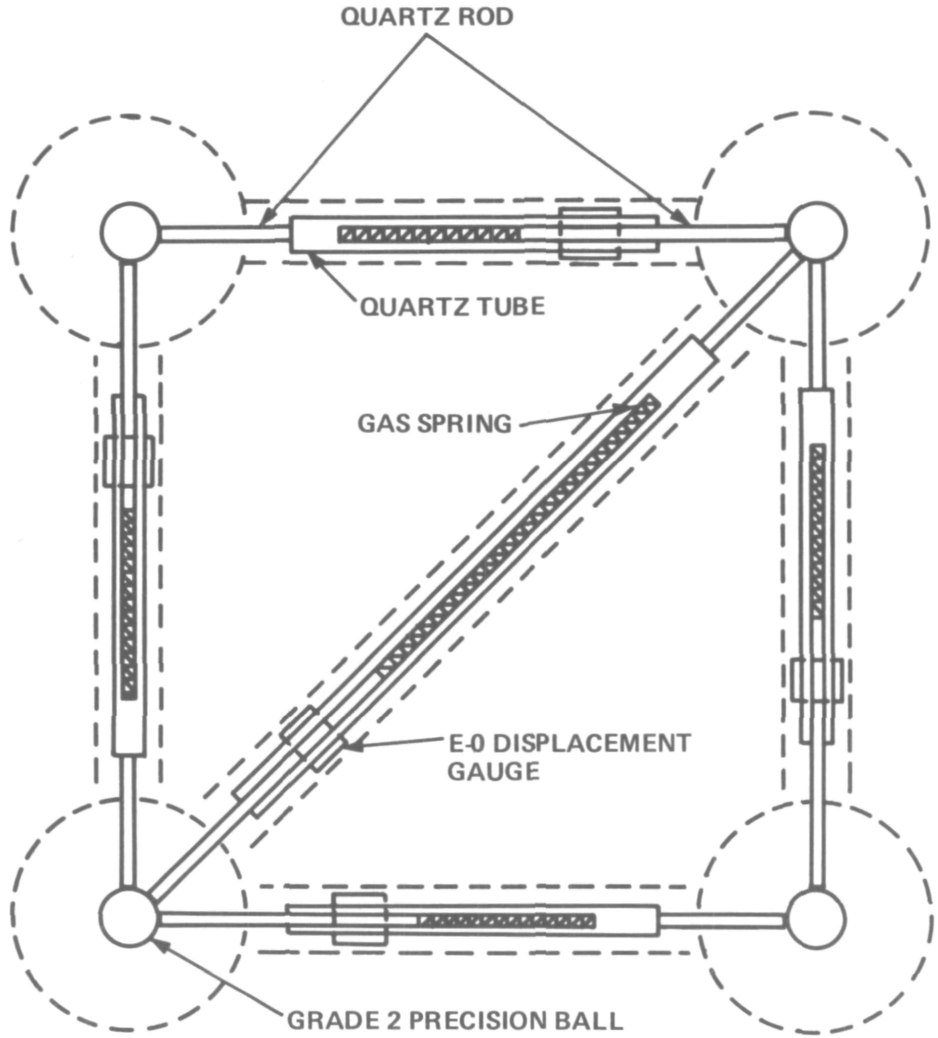


Figure 5

PLATFORM ATTACHMENT (Figure 6)

Three nodes can serve to define the reference plane of an attached platform. This reference plane can be transferred mechanically into the intra-platform alignment system by means of quartz spacers. Micropositioners developing reaction at the exostructure can move the reference nodes as required to meet coordinate control requirements. The endostructural spacer assemblies will follow the balls being moved to maintain the physical internodal link.

The endostructure interfaces with the exostructure primarily through the precision ball suspension. The precision ball can be suspended inside the hollow exostructural ball by a molded-in-place compliant buffer of RTV or similar material. This material will be molded so as to provide a receiving and guiding socket for the termination of the spring-loaded quartz spacer assembly.

PLATFORM ATTACHMENT

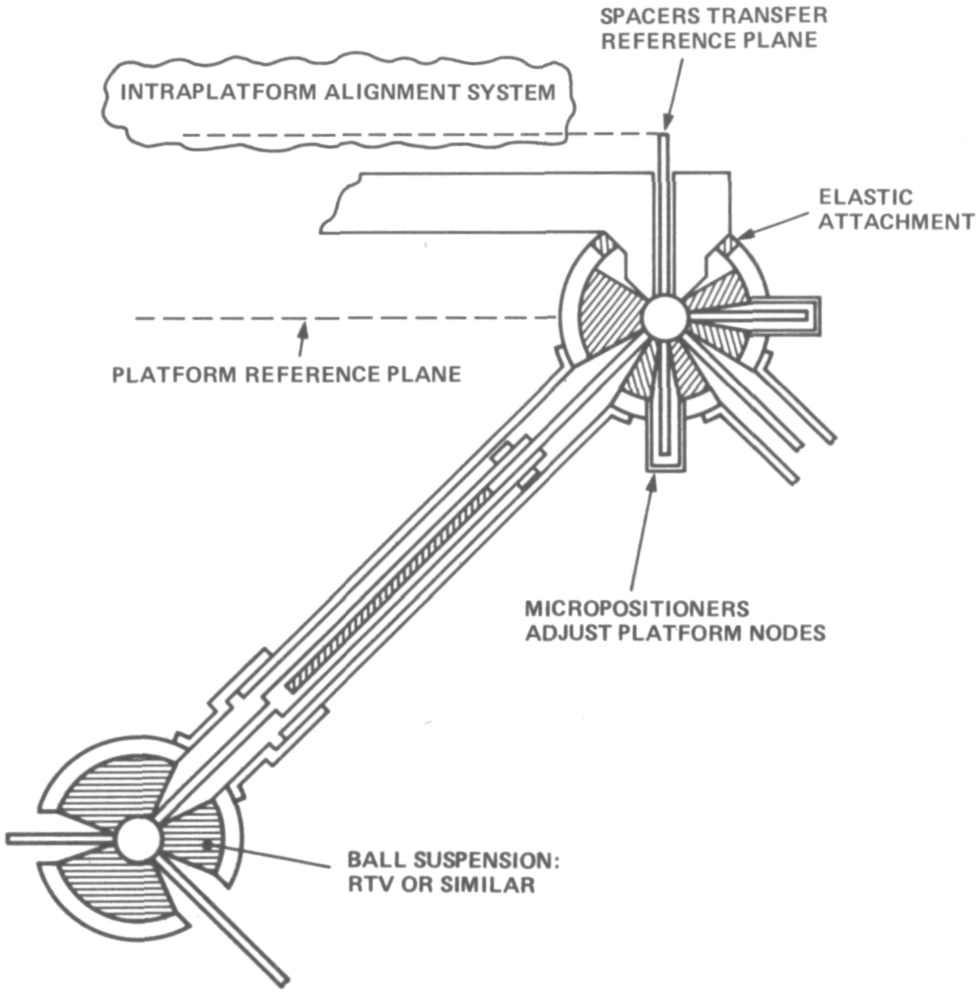


Figure 6

ANTECEDENTS: THE MERO SYSTEM (Figure 7; Figure 8)

A variety of ball-strut exostructural designs are compatible with the PSMS concept. One possibility is an adaptation of an old (circa 1940) German design called the MERO system.

ANTECEDENTS - THE MERO SYSTEM

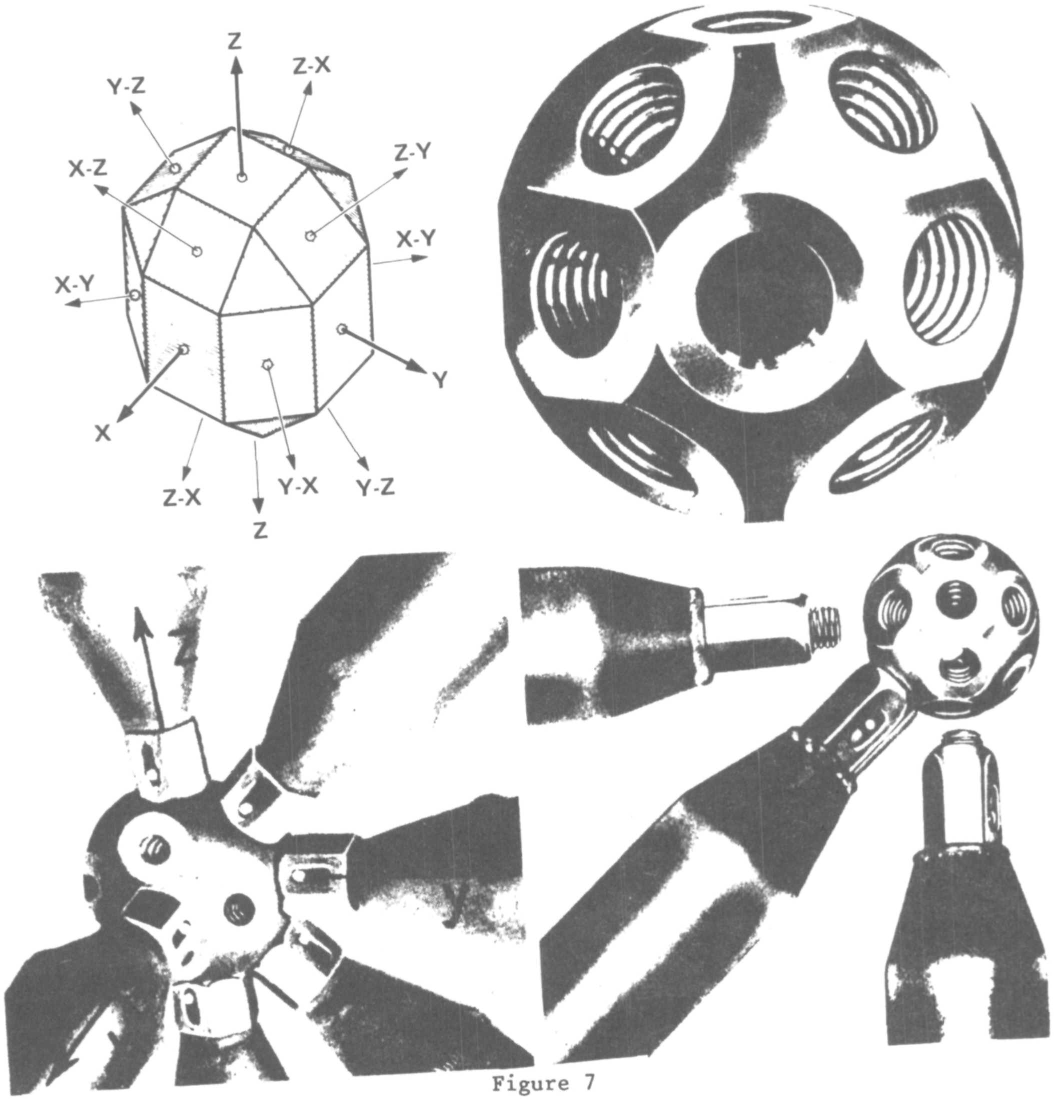


Figure 7

THE MERO SYSTEM (CONT'D)

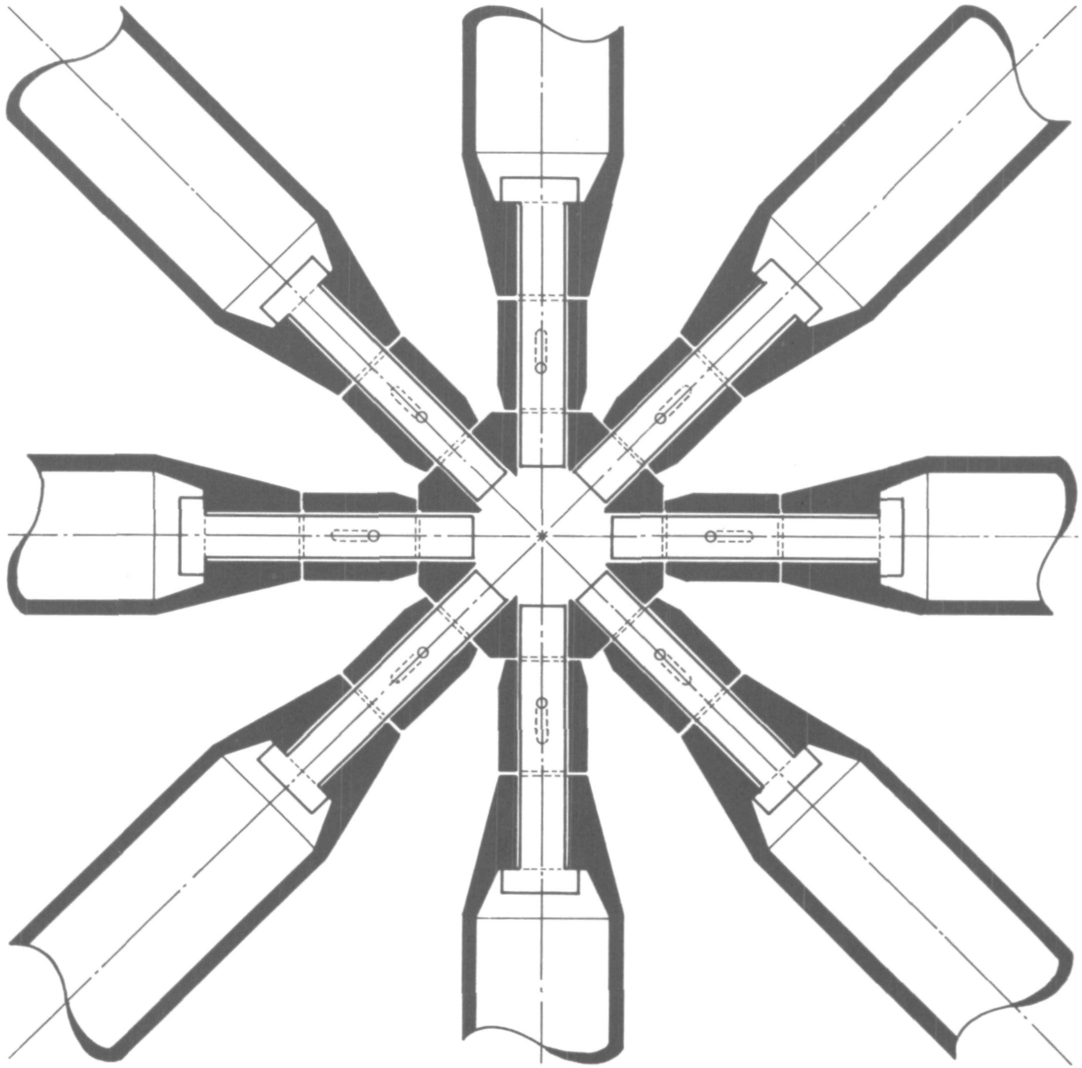


Figure 8

MODIFICATION OF THE MERO STRUT (Figure 9)

As it stands, the MERO design is not completely hollow and is severely overconstrained at the nodes. The joining bolt can easily be made hollow, however, and telescoping and spherical seating features can be added to improve erectability.

MODIFICATION OF THE MERO STRUT

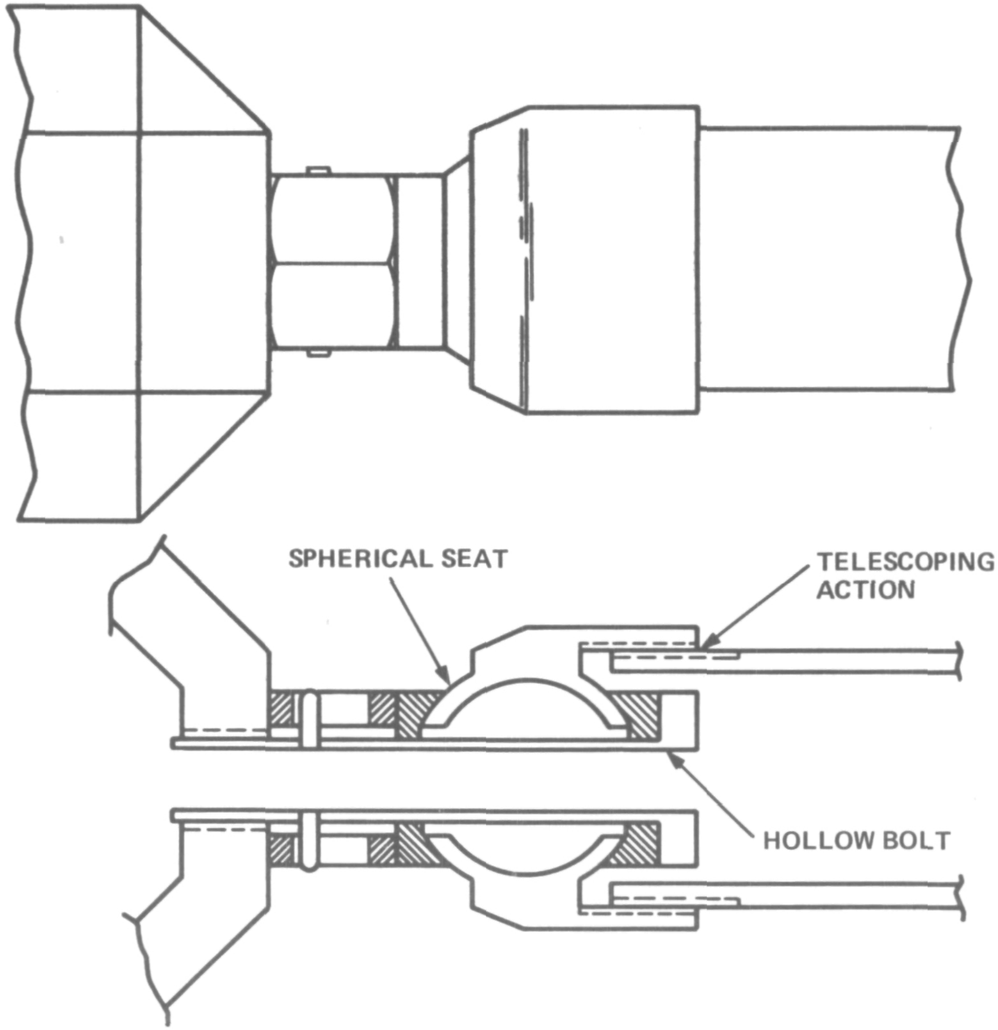


Figure 9

KEY ELEMENTS OF METRICAL ENDOSTRUCTURE (Figure 10)

The length attributed to any internodal link can be differentially affected by several processes, and each must therefore be either avoided or tracked to allow correction. Misalignment of spacer assembly axis and the line connecting the nodes is avoided by means of the socket or guideway molded into the ball suspension. Longitudinal movement of the balls is tracked by the absolute displacement indicator. Changes in the contact force compressing the spacers is tracked by a force transducer. (If the spring is pneumatic, force changes are functions of temperature, and the force transducer can be eliminated.) Temperature changes that alter the physical length of the spacers and balls are tracked by thermistors on all elements.

KEY ELEMENTS OF METRICAL ENDOSTRUCTURE

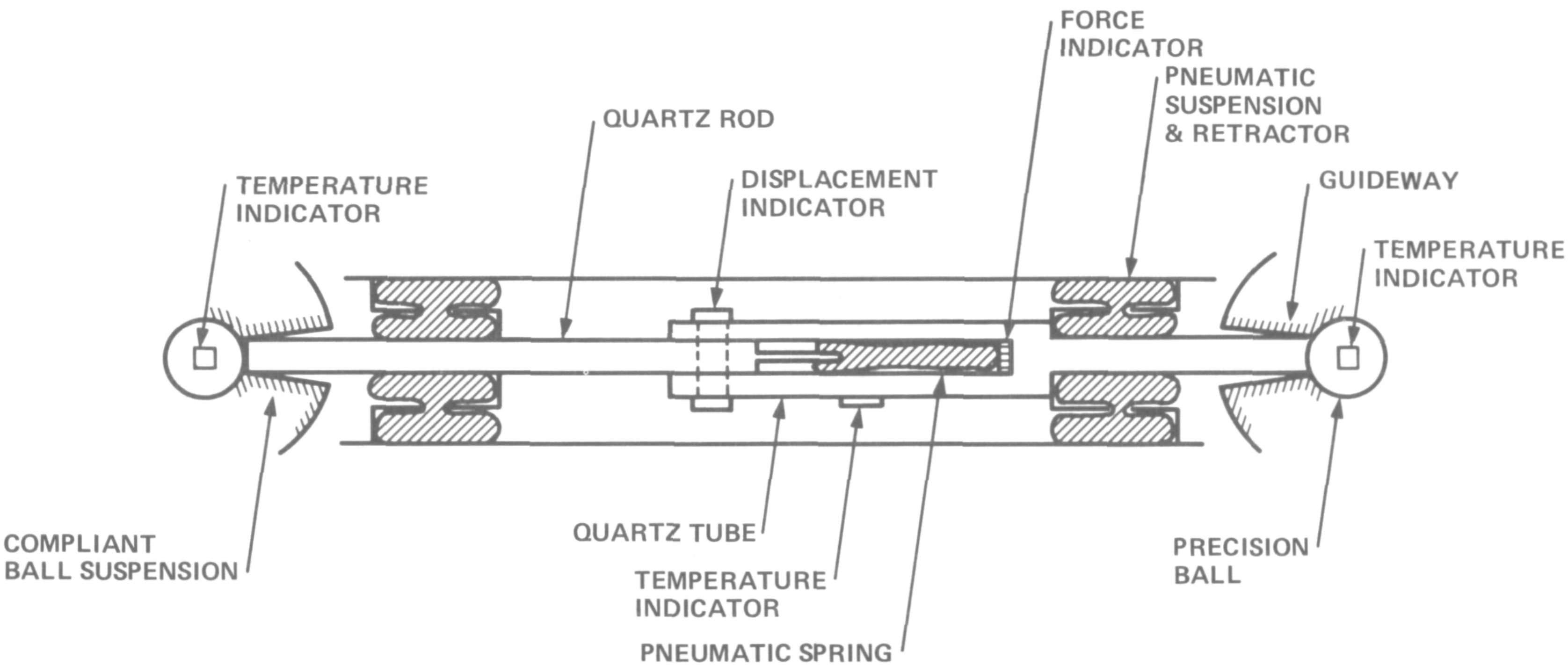


Figure 10

INSTALLATION SEQUENCE (Figure 11)

In the PSMS concept, the spacer assembly is calibrated while mounted in the strut, then retracted, and held pneumatically for storage and shipment. The metrology system is activated during erection simply by releasing the pneumatic suspension and making an electrical connection.

INSTALLATION SEQUENCE

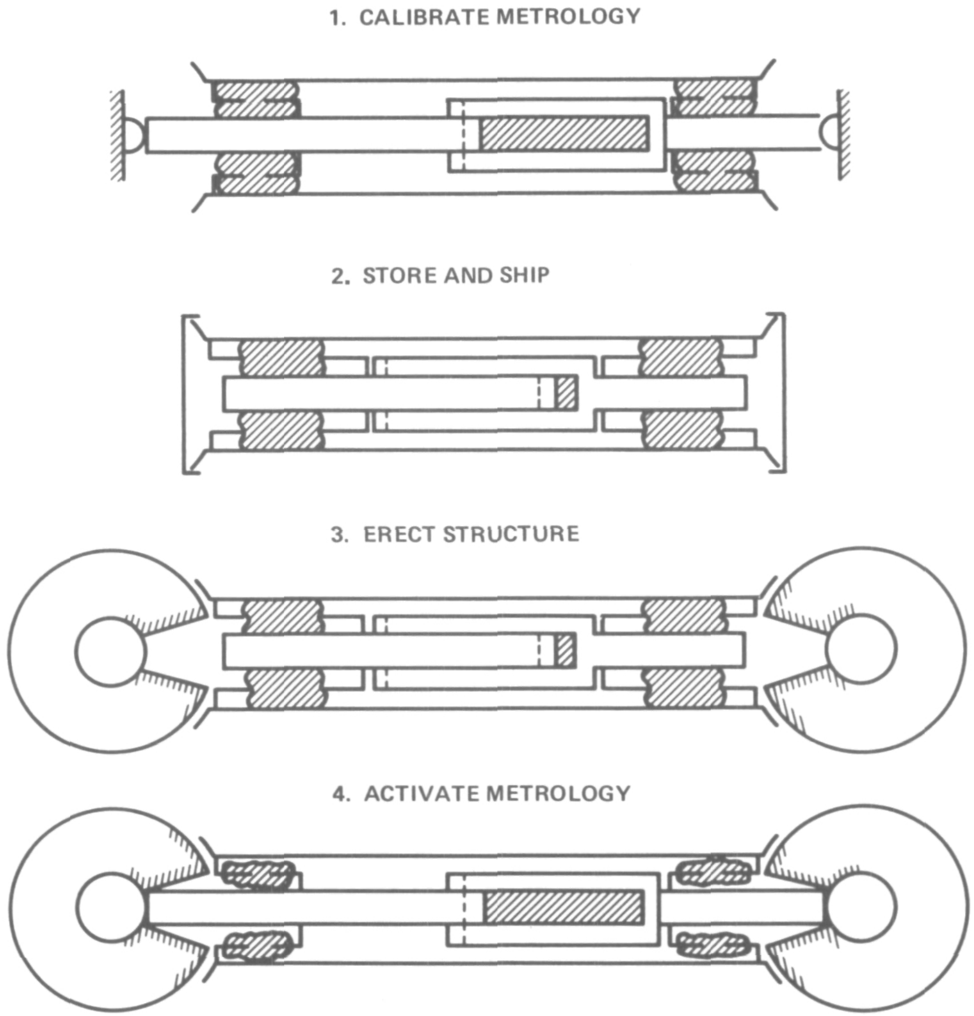


Figure 11

DIMENSIONAL CONTROL HIERARCHY (Figure 12)

In the PSMS concept all dimensional information is traceable to a local physical standard, a glass-ceramic bar. No reference is ever made to any outside measurement, calibration, or standard.

DIMENSIONAL CONTROL HIERARCHY

IN SPACE ← | → IN GROUND LABORATORY

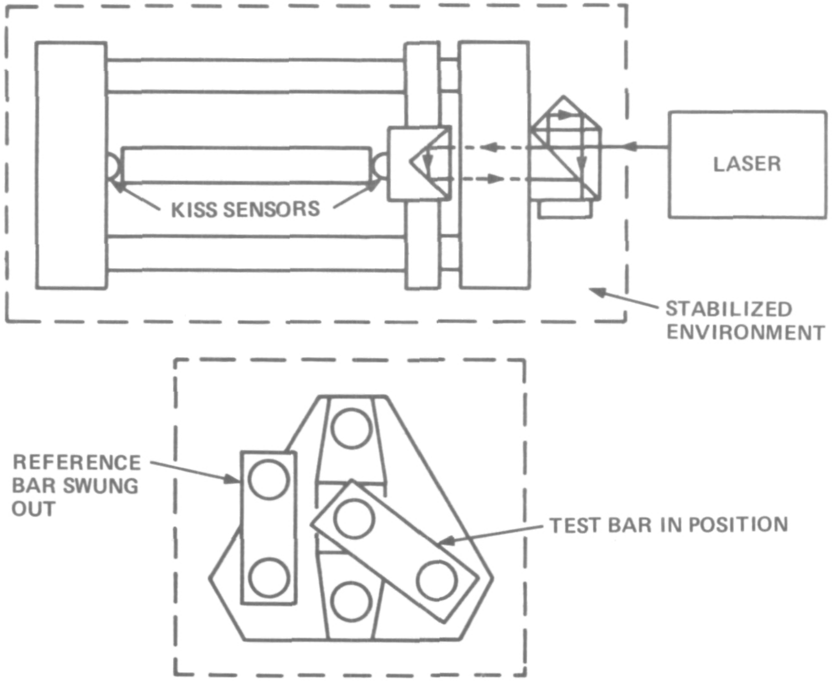
4th LEVEL ON-BOARD COMPUTATION	3d LEVEL ON-BOARD COMPUTATION	2d LEVEL ON-BOARD COMPUTATION	1st LEVEL ON-BOARD COMPUTATION	ON-BOARD INDICATOR READINGS	MAIN CALIBRATION	PRELIMINARY CALIBRATION	SECONDARY STANDARDS	PRIMARY STANDARD
POSITIONER COMMANDS	NODE COORDINATES	CURRENT LENGTH	LENGTH INCREMENTS	DISPLACEMENT, FORCE, TEMPERATURE	BASE LENGTH, CHANGE RATES	ON-BOARD INDICATORS	LABORATORY INSTRUMENTS	CERVIT OR ULE BAR
ΔX	X/S	L/S			$(L/S)_0$		$\lambda(10^{-8})$	S ($\approx$ 3m)
ΔY	Y/S							
ΔZ	Z/S		$\Delta(L/S)_D$	D(L)	$\alpha = \frac{\partial(L/S)}{\partial D(L)}$			
			$\Delta(L/S)_F$	F(L)	$\beta = \frac{\partial(L/S)}{\partial F(L)}$	F(L)		
			$\Delta(L/S)_T$	T(L)	$\gamma = \frac{\partial(L/S)}{\partial T(L)}$	T(L)	$F^{\#}(0.05)$	
						T(S)	T^{o} (0.05)	

Figure 12

BASELINE MEASUREMENT (Figure 13)

It is intended to use a commercial interferometer, the HP-5526A, for all comparisons, if the frequency stability proves adequate. Other lasers with adequate frequency stability can be substituted, if necessary.

BASELINE MEASUREMENT WITH HP-5526A LINEAR INTERFEROMETER



1. REFERENCE BAR OF CERVIT OR ULE APPROXIMATES LONGEST TEST BAR.
2. TEST BAR MEASUREMENTS ALTERNATE WITH REFERENCE BAR MEASUREMENTS.
3. LIGHTPATH INDEX STABILIZED TO $\approx 10^{-9}$ PER COMPARISON TIME.
4. LASER FREQUENCY STABILIZED TO $\approx 10^{-9}$ PER COMPARISON TIME.

Figure 13

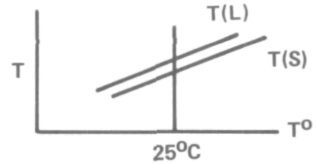
CALIBRATION PROCEDURES (Figure 14)

Calibration of the endostructure is done by interferometric comparison with a local standard under optimum and carefully controlled conditions in a ground laboratory. Baselengths and coefficients are determined from regression lines (or curves) based on many comparisons.

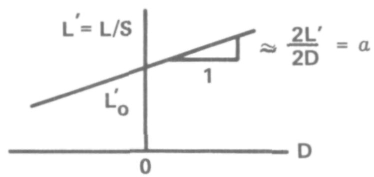
CALIBRATION PROCEDURES

1. PRELIMINARY

CORRELATE T(L) WITH T(S) IN TERMS OF T°(LAB), TO 0.05°C

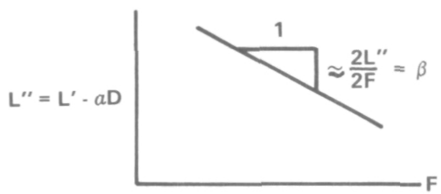


2. BASELENGTH AND DISPLACEMENT GAUGE



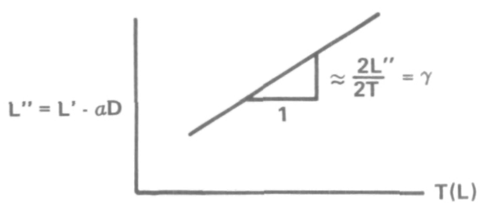
T(L) → T° = 25°C
T(S) → T° = 25°C
F → 1 LB

3. FORCE GAUGE



T(L) → T° = 25°C
T(S) → T° = 25°C

4. TEMPERATURE GAUGE



T(S) → T° = 25°C
F → 1 LB

Figure 14

COMPUTATIONAL SCHEME (Figure 15)

In the PSMS concept, major reliance is placed on computation for in-space dimensional determination and control.

COMPUTATIONAL SCHEME

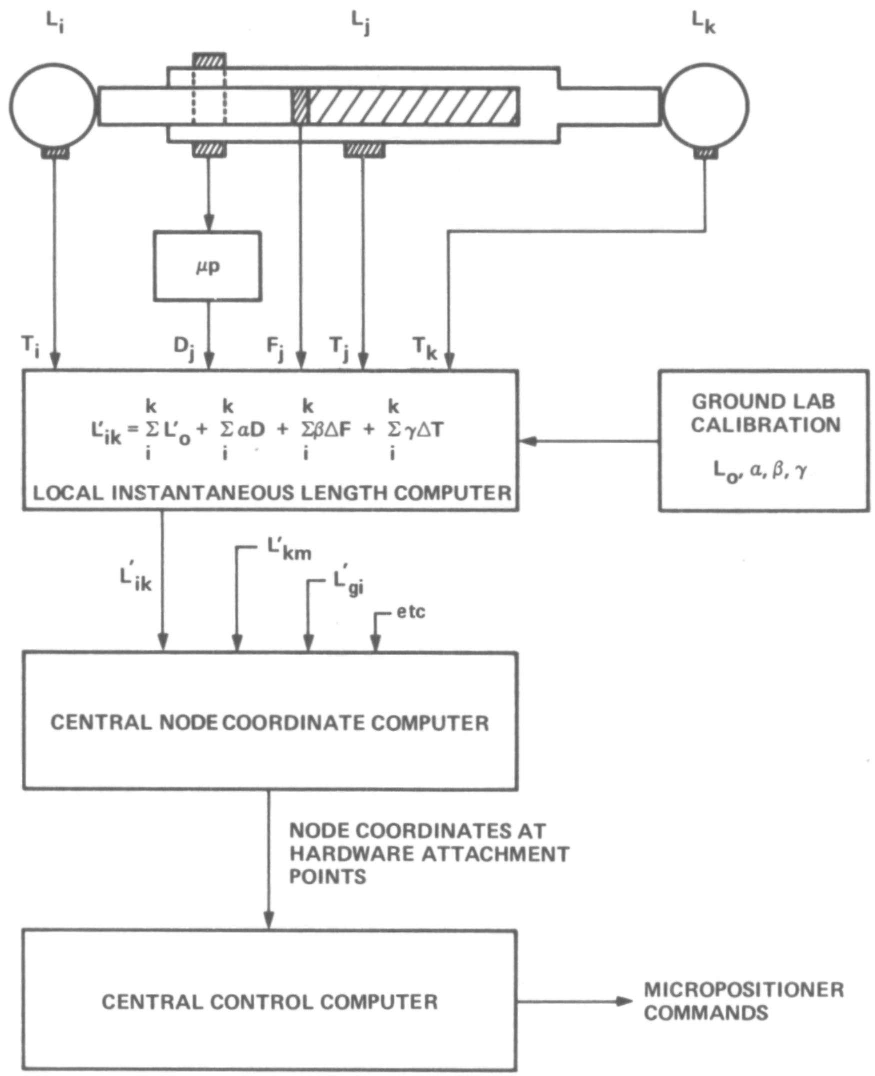
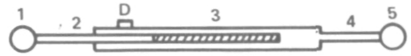


Figure 15

CUMULATIVE ERROR (Figure 16)

A preliminary analysis based on conservative estimates of elementary contributions indicates that the RMS error in attributed internodal length can be held to about 7 microinches for a 10-ft strut. A further analysis of error propagation in 3-dimensional networks (not described here) shows that, provided the figure is strong, RMS coordinate error will cumulate as the square root of the number of links traversed.

CUMULATIVE ERROR IN COMPUTED INTERNODAL LENGTH



$$\sigma_L^2 = \Sigma\, \sigma_{L_o}^2 + \Sigma\, (L\gamma)^2\sigma_T^2 + \Sigma\, (L\beta)^2\sigma_F^2 + \alpha^2\sigma_D^2 + \Sigma\, (L\Delta T)^2\sigma_\gamma^2 + \Sigma\, (L\Delta F)^2\sigma_\beta^2 + (\Delta D)^2\sigma_\alpha^2$$

	UNITS	1	2	D	3	4	5
L_T	IN	0.5	20		100		0.5
L_F	IN	0.5	20		-	20	0.5
A	IN^2	0.1	0.5		0.5	0.5	0.1
E	10^6PSI	30	10		10	10	30
γ_T	$10^{-6}/^oC$	10	0.5		0.5	0.5	10
ΔT	^oC	50	50		50	50	50
ΔF	#	1	1		0	1	1
ΔD	10^{-6}IN			10^5			
γ	$10^{-6}/^oC$	10	0.5		0.5	0.5	10
β	10^{-6}/#	0.3	0.2		0.2	0.2	0.3
α	IN/IN			1			
σ_T	^oC	0.1	0.1		0.1	0.1	0.1
σ_F	#	0.1	0.1		-	0.1	0.1
σ_D	10^{-6}IN			2			
σ_γ	$10^{-9}/^oC$	10	0.5		0.5	0.5	10
σ_β	10^{-9}/#	0.3	0.2		0.2	0.2	0.3
σ_α	10^{-6}IN/IN			20			
σ_{L,L_o}	10^{-6}IN	1		2		. .	1
$\sigma_{L,T}$	10^{-6}IN	0.5	1		5		.5
$\sigma_{L,F}$	10^{-6}IN	-	0.4		-	0.4	-
$\sigma_{L,D}$	10^{-6}IN			2			
$\sigma_{L,\gamma}$	10^{-6}IN	.25	.5		2.5		.25
$\sigma_{L,\beta}$	10^{-6}IN	-	-		-	-	-
$\sigma_{L,\alpha}$	10^{-6}IN			2.0			

$\sigma_L = 6.9\mu IN$

Figure 16

THE PRECISION SELF-METERING STRUCTURE: SUMMARY

STRUCTURE

1. SHUTTLE TRANSPORTABLE
2. EVA OR MANIPULATOR ERECTABLE
3. GEOMETRICALLY VERSATILE
4. USABLE WITH OR WITHOUT METROLOGY
5. LOW PRECISION OF MANUFACTURE
6. WIDE CHOICE OF MATERIALS
7. DEMOUNTABLE AND REUSABLE

METROLOGY

1. PERMANENT, ONE-TIME GROUND CALIBRATION
2. NO SETUP, ALIGNMENT OR CALIBRATION IN SPACE
3. CALIBRATION UNAFFECTED BY STORAGE OR HANDLING
4. INHERENT LONG-TERM PHYSICAL STABILITY
5. NO MECHANICALLY ACTIVE OR DRIVEN PARTS
6. LOW POWER REQUIREMENTS
7. CONVENTIONAL MATERIALS AND COMPONENTS
8. RMS ERROR IN 10 FT LINK $\approx$ 7 MICROINCHES
9. RMS COORDINATE ERROR $\approx$ 7 MICROINCHES X $\sqrt{\text{NO. OF LINKS TRAVERSED}}$

Figure 17