An Engineering Analysis of a New Perturbation Measurement Test Rig

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This paper describes the design, manufacture, commissioning and operation of a new RF cavity measurement system at Daresbury. The system measures the change in magnetic and electric field strengths caused when a small perturbing object is precisely positioned in the beam tube of the cavity. An engineering design has included a comprehensive investigation of the mechanical errors inherent in the system and the paper describes the techniques employed to eliminate or reduce them.

1. INTRODUCTION

Perturbation Measurements

To determine electro-magnetic field distribution properties of Accelerating cavities, perturbation techniques are employed[1]. Slater's perturbation theory[2] states that the resonant frequency of such a cavity is "perturbed" if a metallic object is inserted into its central beam pipe. The amount of perturbation depends on two factors:

° The relative strength of the E and/or H fields in the vicinity of the perturbing object

° The type of object used and whether it is sensitive to either E or H fields, or both.

Therefore the magnitude of E and H fields can be measured indirectly by monitoring the resonant frequency of the cavity as the object is moved in the cavity's interior. The perturbing object can be a metallic needle or disk whose geometry is such that it interacts with either E or H fields and does not perturb the other, these types of objects also give information on field polarisation. Metallic spheres (or beads) perturb both E and H fields, so it is therefore necessary to perform additional measurements using a dielectric bead, which is sensitive only to E fields. In this way the individual components of E and H fields can be identified and then used to interpret longitudinal and transverse impedances.

2. TEST RIG CONFIGURATION

There are many possible test rig configurations which could have been chosen[3][4], perhaps the ideal solution would be to move the cavity while keeping the bead still, thereby avoiding any vibration or cable errors. However this solution tends to be very expensive as machine tool technology would be required to move the cavity.

Considering methods of moving the bead relative to the cavity leads to a choice between horizontal or vertical configurations. Vertical arrangements have the advantage of eliminating cable sag errors, but as most accelerators operate horizontally, supporting the cavities presents some difficulty. Eliminating all vertical designs leads to a a horizontally configured rig two of which are considered below.

a) *Bowtype*, where the bead is suspended on a cable between the arms of a bow, which is mounted on a carriage and moved in three axes.

b) *fixed pillar with cable guidance*, this involves suspending the bead on a cable between two guidance rollers. The guidance units are mounted on 2 stage linear translators giving horizontal and vertical movements. Translation along the axis or the beampipe is effected by pulling the cable off a tension drum using a linear translation unit.

Bowtype (Figure 1) has the advantage of eliminating cable sag errors, but requires the cable to be twice the length of the cavity to be tested. This type requires only three translation stages and no elaborate wire guidance system, however the bow arms need to be substantial and the translators fairly heavy duty (expensive) to avoid vibrational and other problems.
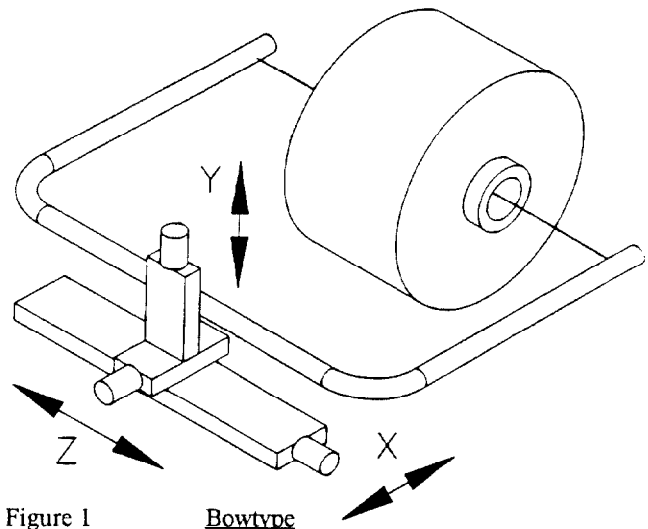

Figure 1   *Bowtype*

Fixed Pillar (Figure 2) This minimises the length of the unsupported cable and decouples the translation along the beam tube from the horizontal and vertical drive motions. This allows the use of inexpensive light duty translation stages. Against this, two additional linear drives are needed along with a sophisticated cable guidance and tensioning system.

In conclusion the fixed pillar type was chosen, because it minimised the unsupported cable length.
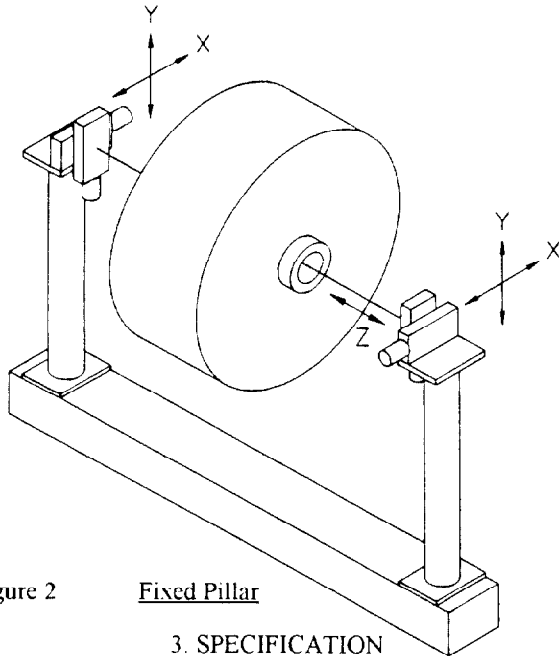
Figure 2   Fixed Pillar

3. SPECIFICATION

a.   Accuracy/repeatability < 0.5mm

b.   Working envelope 100 mm x 100 mm x 1500 mm

c.   Fully automated measurement controlled from a pc.

d.   To use cables of 1 mm diameter and below

e.   Cable tension constant and adjustable up to 100 Newtons

f.   Must have an effective method of aligning the cavities to the Test Rig.

4. REALISATION

In order to realise the test rig to the stated specification it was necessary to provide the following features:

a.   A Stable Structure - Implemented by using granite beds and rigid aluminium pillars

b.   Temperature Controlled Environment - Rig sighted in a dedicated (air conditioned) room and remotely operated. through viewing windows.

c.   Accurate linear translation stages using ball screws and ball bushings on ground shafts

d.   Cable guidance system giving precise and repeatable positioning of the cable. Making use of ball bearings. ground guide wheels and shafts.

e.   Constant cable tension. Uses tension measurement and control through a servo motor driven winding drum.

f.   Software techniques to compensate for cable sag and predictable geometry changes.

g.   Precise location of the bead on the cable. This makes use of a setting jig which aligns the bead

h.   Cavity alignment to the cable - This technique eliminates some of the errors in the rig.

5. SPECIAL FEATURES of the design

a) _Software compensation for cable sag error_. The deflection of the bead is dependant upon two loads as illustrated in Figure 3 below
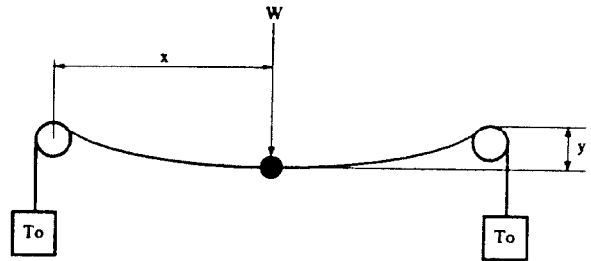

Figure 3

The deflection due to the weight of the kevlar cord which is given by:

$$y_c = (To/\mu) (\cosh (\mu x/To) - 1) \qquad (1)$$

and the deflection due to the point load caused by the weight of the bead:

$$Y_b = (Wx)/To \qquad (2)$$

These two formulae combined will give the total deflection of the bead which is

$$y = (To/\mu) (\cosh (\mu x/To) - 1) + (Wx)/To \qquad (3)$$

Where

To = Tension (N)

x   = Distance from support to bead (m)

μ = Weight per unit length of cable (N/m)

Using this formula. a graph showing the predicted deflection to the mid-point can be drawn. Some typical results are shown in the Figure 4 for a bead weight of 10g and a span of 1.5m.
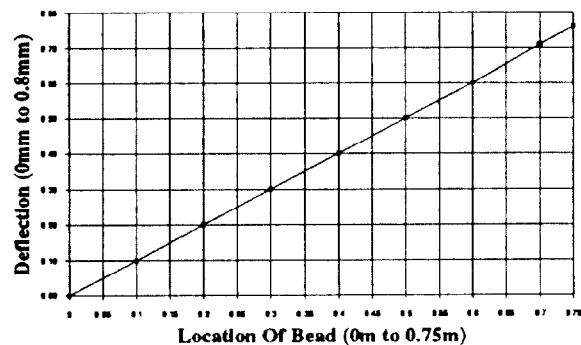

Figure 4

By taking these into account and using the above equation cable sag can be compensated for automatically. Alternatively look up tables can be generated or measured experimentally.

b) Software Compensation for changes in cable length due to the relative movements of the cable pulling translator and the first cable guidance pulley.
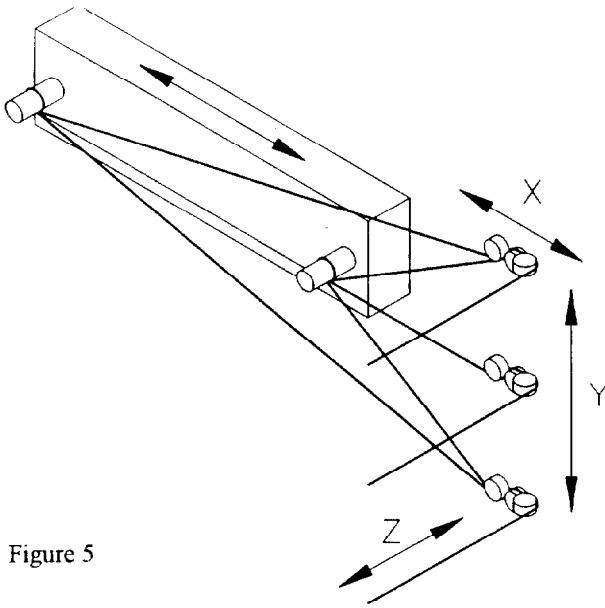

Figure 5

$$a = \sqrt{((z + x)^2 - y^2)} \qquad (4)$$

Where a = distance between centres of the cable pulling translator and x-y guiding unit pulley.

z = position of the bead along the beam tube axis.

x = position of the bead in the horizontal plane perpendicular to the z axis.

y = position of bead in the vertical plane perpendicular to the z axis.

This relationship is embedded in the control software and is invisible to the user of the Rig.

c) Tension Control It is apparent that close control of the cable tension is required to ensure that the bead remains in the set position. The system used in this case is a strain gauge transducer which measures the tension in the cable and feeds into a servo motor control loop acting on the winding drum. This has the ability to compensate for the winding drum and other inertial loads in the system, helping to eliminate potential sources of vibrations.

6. VIBRATION/RESONANCE

Preliminary experiments with beads suspended on tensioned cables revealed that lightly tensioned cables have relatively low resonant frequencies which have long decay times while highly tensioned cables have correspondingly higher resonant frequencies and greatly reduced decay times. However, these high tension loads increase the size of the mechanical components needed to carry them and can lead to cable breakage problems.

Methods of damping vibrations in the cable have been considered. It is hoped that this will be unnecessary, however, provision has been made on the guidance blocks to mount diaphragm damping units. Possible sources of vibration were considered throughout the design process particularly in the area of the linear drives and cable tensioning systems.

7. CONCLUDING REMARKS

The Rig has been assembled and is currently being commissioned. An on axis measurement of a new RF Cavity has been successfully made, the results of which have been included in a paper by P Macintosh[1]. Much more work is required before a full assessment of the Rig's capabilities will be known.

8. ACKNOWLEDGEMENTS

9. REFERENCES

[1] PA McIntosh, "Perturbation measurement on RF cavities at Daresbury", EPAC 1994.

[2] Microwave Electronics, JC Slater, Van Nostrand Princeton, NJ, (1950)p81.

[3] Automated Bead Positioning system for Measuring Impedances of RF Cavity Modes by DA Goldberg and RA Rimmer, LBL, Berkeley, CA 94720.

[4] Precise Perturbation measurements of Resonant Cavities and HOM identification by F Caspers and C Dôme CERN presented at Conference on Precision Electromagnetic Measurements, Delft Neth 20-24/8/84.