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DESIGN AND FABRICATION OF MEASUREMENT RIG TO MEASURE THE GEOMETRICAL IMPERFECTIONS OF THIN CYLINDRICAL SHELLS

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Abstract: *It is well known that the buckling strength of thin cylinder shells are mainly depends upon geometrical imperfections present on the thin cylindrical shells induced during manufacturing process. Hence it is necessary to measure these geometrical imperfections accurately, to predict the buckling strength of the cylindrical shells accurately. Using CMM to measure the geometrical imperfections is more accurate but costlier and also measurement depends on the operator's skill. To overcome this problems an imperfection measurement rig is developed Using this measured imperfections data best fit surface map is generated, which can be used for further analysis.*
Keywords: *Thin Cylindrical shells, radial geometrical imperfection, surface imperfection map, imperfection test rig.*

1. INTRODUCTION

The need for measurement rig is that the manufacturing of thin cylindrical shells without any imperfections are very difficult; these initial geometrical imperfections (means even slight deviation from perfect geometry) can reduce the load carrying capacity of the thin cylindrical shells (r/t ratio>20, where r and t are radius and thickness of the thin cylindrical shell respectively) drastically. So to predict the buckling strength of thin cylindrical shell exactly, it is necessary to measure the geometrical imperfections accurately. Thousands of readings have to be taken on the surface of the thin cylindrical shell to measure the geometric imperfections. Using CMM for this purpose is costlier and also measurement depends on the operator's skill and fatigue of the operator. So, to overcome this problem, the imperfection measurement rig is developed.

2. LITERATURE REVIEW

Singer and Abramovich (1995) in their survey on development of imperfection measurement techniques stressed the importance of initial geometrical imperfections and the use of the data in the design of structures for applications in the following words: "If we do not know the imperfections and the boundary conditions, we cannot improve our predictions of the buckling loads, no matter how sophisticated our codes are and how large and how fast our computers become".

During the early days of experiments on buckling of shells, the initial geometrical imperfections were not measured, probably due to ignorance of influence of initial geometrical imperfections on reducing the buckling strength. Systematic imperfections measurements were carried out initially on laboratory-scale models and then followed by measurements on large-scale and prototype structures. The first automated system for this purpose was developed at the California Institute of Technology (CALTECH) (Arbocz and Babcock, 1969). The CALTECH system used a non-contact inductance type transducer and is referred to as GALCIT in the literature. Subsequently, similar to GALCIT, a system was established at Technion, Haifa, Israel by Singer in the year 1974 (as given in Ref. (Singer and Abramovich, 1995). In this test rig, a simple contact probe of linear variable differential transformer (LVDT) was used for imperfection measurement. Miller and Grove (1986) carried out imperfection measurements on two large torispherical head models using a specially designed frame with 15 LVDTs on the rotating arm. In case of large size cylindrical shells and if on site measurements had to be taken, measurement system based on **LVDT**s were used for imperfection measurements. For example, Abramovich *et al*, (1987), Xiaoli *et al* (1996), Carvelli *et al* (2001), Pircher and Wheeler (2003), Athiannan and Palaninathan (2004) used LVDT based imperfection measurement systems to measure the geometrical imperfections. Recently, in case of small cylindrical shells and if measurements are carried out in laboratories, laser scanning technique is used for imperfection measurements (for example, Piening *et al* (1995), Ding *et al* (1996), Chryssanthopoulos *et al* (1999). Ding *et al* (1996) used specialised surface – profile measurement apparatus consisting precision theodolites and associated software packages for data processing and analysis for accurate measurement and analysis of large cylindrical shells such as silos and tanks.

O'Shea and Bridge (2000) measured imperfections in circular tubes and box sections prior to compression tests with voltage displacement transducers. An investigation relating to the methods of measurement and assessing the geometrical imperfections on the cold rolled thin walled steel panels was carried out by Bernard *et al* (1999). The measurement procedures investigated includes close range photogrammetry, precise optical leveling and the use of coordinate measurement machine (CMM).Finally it was recommended that the use of CMM yields desirable results with high precision. Hence authors initially tried to measure the distributed geometrical imperfections with or with out dents present on the cylindrical shells with a high precision CMM. Later it is realized that the accuracy of the measurement depends upon operator's skill and operator's fatigue to measure thousands of such imperfection data if CMM is not an automated one. Hence, in this work an imperfection measurement rig is designed and fabricated to hold the test cylindrical shell and micron dial indicator to measure geometrical imperfections. Using this simple and cost effective imperfection measurement system the distributed geometrical imperfections with or without dents present on the cylindrical shells is measured.

3. DESIGN CONSIDERATIONS

The main aim of measurement rig to assist the measurement of geometrical imperfections which can be measure either on internal or external cylindrical surface. Since measurement of imperfections on external surface is much easier than internal surface, in this work the test rig is developed to measure the geometrical imperfections on external surface only.

The factors are considered for design of the test rig.

1. The test rig should be designed in such a way that once the test cylindrical shells and imperfection measuring instrument (micron dial indicator) is loaded on the measurement rig, both of them should not be disturbed until the complete measurement is carried out.
2. A specimen holder is to be designed for holding test thin cylindrical shells of size internal diameter 95.4 mm, length 150 mm and wall thickness 1 mm.
3. The test cylindrical shell together with specimen holder should be rotated freely about its axis of rotation for every 5 degrees.
4. A dial holder is to be designed to hold the measuring instrument and also it should be moved along the longitudinal and transverse directions of thin cylindrical shell and also it can be clamped at any desired location rigidly.

4. COMPONENTS OF MEASUREMENT TEST RIG

The designed and fabricated measurement test rig includes three major parts as shown in Fig. 1. They are

(a) Main frame with centres
  (1) Bottom base plate
  (2) Top base plate
  (3) Centre support
  (4) Revolving centre
  (5) Guide block
  (6) Indexing plate
  (7) Adjusting screw
  (8) Screw holding plate
  (9) Lock screw
  (10) Column
  (11) Indexing pin
(b) Specimen holder
  (1) Locating mandrel
  (2) Flange retainer
(c) Dial holder
  (1) Saddle
  (2) Lock plate
  (3) Transverse slide

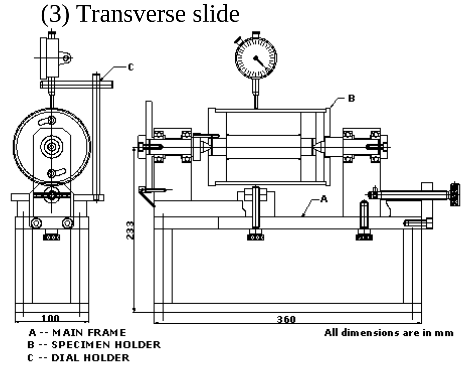


Fig.1 Components of measurement test rig

4.1. Main Frame with Centres

The photographic view of the main frame with centres is shown in Fig. 2.The main frame consists of a bed with a guide ways supported on four columns. On one side of the bed a fixed live centre with indexing mechanism is rigidly fixed and on the other end of the bed a movable live centre is mounted.

Fig: 2 Photographic view of mainframe with centres

This movable live centre can be moved back and forth on the guide ways by ball screw mechanism and it can be clamped at any location on the bed. The indexing plate consists of 72 holes, so as to index the test cylindrical shell for every 5^o about the axis of between centres.

A pin – hole mechanism in conjunction with indexing mechanism is used to locate the test cylindrical shell for every 5^o in circumferential direction. A dwell pin attached with the fixed live centre is used to transmit positive motion between indexing plate and test specimen.

4.2. Specimen Holder

This is used to mount a test cylindrical shell in between centres. This has a mandrel with a fixed flange at one end. The fixed flange has step projection for 5mm on its face is used to locate the test cylindrical shell and this step projection has sliding fit with the ID of test cylindrical shell. Another guide flange nearer to other end of mandrel is also used to locate the test cylindrical shell. The guide flange also has flat relieved milled surface to avoid interference with dent on the cylindrical shell. The OD of this guide flange also has clearance fit with the ID of the test specimen.

The specimen holder also has a removable clamp flange which has a step projection for 5 mm to locate the clamp flange by test specimen. After locating the test cylindrical shell and clamp flange, both are held together on the mandrel by clamp screws.

4.3. Dial Holder

It is planned to measure the imperfections on the cylindrical shell by using a Mitutoyu Digital micron dial indicator. The dial holder is designed such a way that it can hold the dial indicator and at the same time ensures constant pressure on the dial indicator probe. It has two major parts namely saddle and holding stand.

The saddle can be moved back and forth longitudinally on the bed with the help of the guide way of the bed on the main frame. The saddle also has transverse slide ways to move the dial indicator stand in the transverse direction. Both saddle and transverse slide or clamped together on the bed, so as to restrain the motion of dial holder on both the direction. The longitudinal location of saddle is measured with the help of vernier caliper. On one end of the transverse slide commercial available dial indicator stand is retrofitted which can provided 3 rotational degrees of freedoms for the dial indicator.

4.4. Assembly of the Measurement Rig

The major three parts are assembled together to form measurement rig as shown in Fig.1. The micron dial indicator is fixed in the dial holder. The dial holder on the guide ways is locked by lock screw with lock plate at any desired location.

5. CHECKING THE ACCURACY OF THE FABRICATED TEST RIG

Two important aspects of measurements are checked as per IS 5980-1978

5.1. Checking for Coaxiality of centres (Run Out)

A cylindrical test mandrel of size ø25mm and 180mm length is mounted in between centres. The run out readings are taken at two extreme position of the test mandrel and it is found to be within 0.002 mm

5.2. Checking for Parallelism of axis of centres with respect to Guide ways.

A micron dial indicator is moved along longitudinal axis of the test mandrel close to the end of the mandrel and Parallelism between centres is found to be within 0.004 mm.

6. STEPS FOLLOWED FOR IMPERFECTION MEASUREMENTS

1. A thin cylindrical shell test specimen for imperfection measurement is inserted into the fixed flange such that the dented portion of the cylindrical shell faces the milled portion of the guide flange.
2. The flange retainer is inserted into the other end of the cylindrical shell and locked using Allen screws.
3. This entire specimen holder setup is then mounted in between the revolving centres by adjusting the moving guide block with the help of the adjusting screws and lock screw.
4. The dial indicator is fixed to the dial holder and moved to the one end of the cylindrical shell and locked using the lock screw.
5. The top most peak of the cylindrical shell is identified and dial indicator reading is set to zero.
6. Then, cylindrical shell is rotated in clockwise direction with the specimen holder for every 5 degrees using the indexing plate and indexing pin and dial indicator readings (imperfection measurements) are noted.
7. The saddle is moved along the longitudinal direction of the cylindrical shell for every 10mm (nearer and on the dent every 2mm) and up to other end of cylindrical shell and then locked using the lock screw. Again the imperfections are measured in circumferential direction as stated in the above step.
8. Both the specimen holder and the dial indicator should not be disturbed until the complete measurement is carried out.

7. GEOMETRICAL IMPERFECTION SURFACE PLOTS

Using this specially fabricated imperfection measurement rig, measurement of imperfections was carried out on six test cylindrical shells. Out of these, two test cylindrical shells have a circumferential dent, other two tests cylindrical shells have a longitudinal dent and the rest two test cylindrical shells have no dents. But only three test cylindrical shells, imperfection surface plots are shown in Fig.3.

Table: 1 imperfection measurement data in microns (μm) taken from test cylindrical shell without dent.

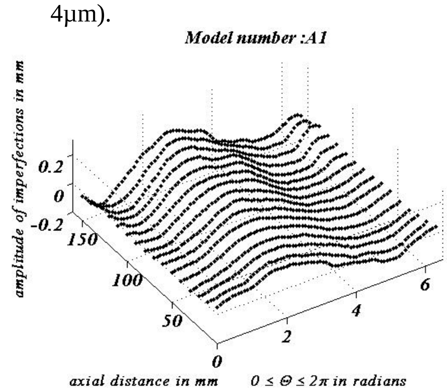
		Longitudinal location in mm					
Circumferential location in degrees		**0**	**10**	**20**	**29**	**40**	**50**
	0	0	-24	-38	-56	-50	-44
	5	6	-21	-37	-52	-47	-41
	10	16	-18	-33	-45	-46	-39
	15	22	-14	-28	-39	-42	-38
	20	29	-6	-23	-33	-40	-34
	25	35	-2	-16	-31	-37	-33
	30	37	2	-13	-28	-34	-32
	35	38	5	-8	-24	-28	-31
	40	38	9	-2	-16	-22	-28
	45	40	10	1	-9	-18	-23
	50	41	11	3	-3	-9	-15
	55	44	12	8	3	2	-5
	60	51	16	17	9	11	7
	65	59	26	22	20	20	19
	70	70	39	33	33	31	34
	75	80	50	45	41	47	45
	80	90	63	55	50	56	55
	85	99	74	65	61	67	70
	90	103	78	74	70	76	80
	95	109	84	81	75	84	86
	100	109	95	85	84	92	92

Fig.3 (a) shows the imperfection surface map of test cylindrical shell without dent (i.e., containing distributed geometrical imperfections) and Table 1 shows sample of imperfection measurement data in microns taken from same test cylindrical shell.(only part of the imperfection data is shown)

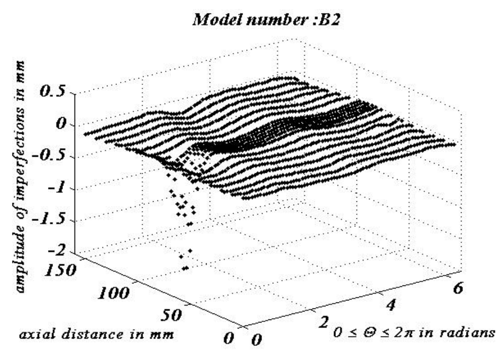
The geometrical imperfections (radial in and out displacements with respect to perfect cylindrical shell) shown as imperfection surface map in Fig. 3 can be converted into equivalent mathematical form using double Fourier series or some other numerical form, from which Finite Element (FE) cylindrical shell models using actual measurement of imperfections can be generated. This FE models can be further analysed to determine its buckling strength.

8. CONCLUSION

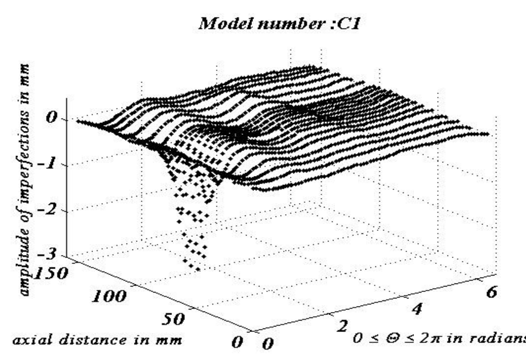
1. The measurement test rig developed satisfies all the specifications stipulated by IS: 5980 - 1978 code.
2. Using this cost effective imperfection measurement test rig designed and fabricated. The imperfection measurements are carried out successfully with an accuracy of ±0.004mm (± 4μm).



(a)



(b)



(c)

Fig.3. Surface imperfection plots of measured geometrical imperfection data taken from test thin cylindrical shell (a) without dent (b) with circumferential dent and (c) with longitudinal dent respectively.

3. Using radial imperfections measurements, imperfection surface maps are generated and using these maps, the equivalent double Fourier series mathematical surfaces can be obtained. These mathematical imperfection surface representations can be used to develop FE models with actual measurement of imperfections.
4. The present measurement rig support only manual measurement technique and in future, the complete imperfection measurement set up can be automated by indexing the cylindrical shell and moving the dial holder along the longitudinal direction of test cylindrical shell using stepper motors with provision to store angular, axial and radial displacement of measurement probe.

9. REFERENCES

Abramovich, Yaffe R and Singer (1987), Evaluation of stiffened shell characteristics from imperfection measurements" *Journal of Strain analysis*, Vol22 (1), pp 17-23.

Arbocz J and Babcock Charles D.Jr. (1969), The effect of general imperfections on the buckling of thin cylindrical shell, *Journal of Applied Mechanics – Transactions of ASME*, Vol.36, pp 28-38.

Athiannan K and Palaninathan R. (2004), Experimental investigations of buckling of cylindrical shells under axial compression and transverse shear, *Sadhana*, vol-29, pp.93-115.

Bernard E.S, Coleman. R and Bridge R.Q (1999),"Measurement and assessment of geometrical imperfections in thin walled panels", Thin walled structure, Vol.32, 103-126.

Carvelli V, Panzeri N and Poggi C (2001), Buckling strength of GFRP under-water vehicles, *Composites Part B: Engineering*, Vol.32 (2), pp 89-101

Chryssanthopoulos M.K., Ellghazouli A.Y and Esong I.E (1999), Compression tests on antisymmetric two-ply GFRP cylinders ", *Composites Part B*, Vol.30, pp335-350

Ding X.L., Coleman.R and Rotter J.M (1996), Technique for precise measurement of large scale Silos and tanks, *Journal of Survey Engineering*, Vol.122 (1), pp15-23.

IS: 5980-1978(Reaffirmed 2005), Specification for bench Centres.

Miller C.D and Grove R.B (1986), Pressure testing of Large scale torispherical heads subjected to knuckle buckling", *Int. J .Pressure vessel and Piping*, Vol.22, pp174-179.

O'shea M.D and Bridge R.Q (2000), Design of thin concrete filled tubes, *Journal of structural Division ASCE*, Vol.126 (1),pp1295 -1303.

Piening H.R, Meyer and Anderegg R. (1995), Buckling and post buckling investigations of imperfect curved stringer-stiffened composite shells. Part A: experimental investigation and effective width evaluation, *Thin Walled structures*, Vol.23 (1-4),pp 999-1014.

Pircher M. and Wheeler.A (2003), The measurement of imperfections in cylindrical thin-walled members, *Thin-Walled Structures*, Vol. 41(5), pp 419-433.

Singer Josef and Abramovich Haim (1995), the development of shell imperfection measurement techniques, *Thin walled structures*, vol. 23, pp 379-398.

Xiaoli D, Coleman R and Rotter J M (1996), Techniques for precise measurement of large-scale silos and tanks, *J. Survey. Eng*. Vol.122, pp14–25