DEVELOPMENT OF CFRP PRECISION GANTRY BEAMS FOR 11TH GENERATION LCD PANEL MANUFACTURING

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1. Introduction

For precision manufacturing machine tools the load bearing components are generally made of rigid conventional materials for higher structural stiffness, increasing the overall weight of the systems. Mass reduction of the component without compromising the stiffness of the structural member is advantageous.

In order to match the demand of the growing semiconductor industry, particularly the increasing demand of bigger flat screen LCD monitor, the LCD manufacturing industry is seeking larger stage system for production of larger LCD monitors. Because of this reason there is a fast change in the LCD manufacturing industry. As of now 10th generation stage system is operational however research and development for larger, safer and energy efficient stage system is being conducted. See table 1 for the details of the stage generations.

In this study, parametric study of hollow gantry beams (M1-M4) designed and developed for 11th generation Liquid Crystal Display (LCD) panels manufacturing were studied. The 11th generation LCD panel measures 3000mm in length and 3320mm in the width which will be used for the manufacturing of LCD screens more than 70 inches wide. In order to be used for high precision LCD manufacturing the beam should be adequately stiff. A lighter beam is desired for rapid motion and to make the system energy efficient. Precision beams of laminated carbon fiber reinforced plastics (CFRP) were designed, numerically analyzed, fabricated and experimentally tested for deflection, flatness and straightness under the operating conditions.

The use of CFRP composites to upgrade structures and, in particular, to construct lighter but stiffer beams has wide applications [1, 2]. Laminated composites are usually manufactured from unidirectional and woven plies of a given thickness. Stacking sequence optimization is a combinatorial problem that consists in finding the appropriate layer orientations and the associated stacking order. Usually laminated plate optimization methods are used to optimize and design composite structure. A recent review on laminate optimization can be found in [3, 4]. The optimization of composite structure lies in combining reliable Finite Element (FE) modeling with an efficient optimization method adapted to composite design [5]. In this study, parametric optimization of the gantry beams were done using finite element commercial tool, ANSYS [6].

In the present paper, a composite gantry beam is optimized for maximum stiffness (min deflection) and minimum mass. The permissible deflection of the gantry beam for the LCD manufacturing in the study at center is 40μm under 150 kg load at the center along the length of beam. The optimizing parameters of the beam under current study were beam cross-sections, lamination sequences, lamination angles and wall thickness.

Table 1. Comparison of LCD glass substrate size for some earlier generation [7]

Generation	LCD glass substrate size		Year
	Length(mm)	Breadth(mm)	
8	1870	2200	2005
9	2160	2460	2006
10	2850	3050	2009
11	3200	3600	-

2. Model description

The assembled CFRP beam consists of three linear motor (LM) guides, two support bases; one on each ends of beam, and an aluminum carriage (which supports the optical devices for LCD manufacturing). The aluminum carriage travels along the length of beam on the LM guide with 1G acceleration. All the four models differ in cross-sections. Figure 1 shows the four models (M1~M4). M4 has aluminum ribs attached at each corner of the hexagon (shown in thick line).

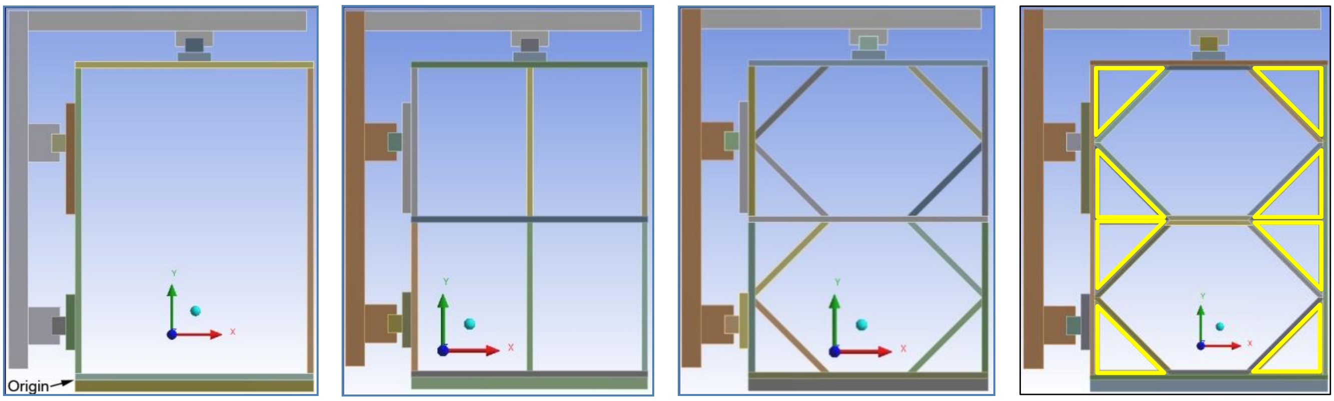
Each of the model analyzed were 4m long (z-axis) with a cross-section of 300 mm and 400 mm for breadth (x-axis) and height (y-axis) respectively. Two linear guides were attached to the right end of the beam 80 mm away from the top and 60 mm from bottom surfaces, and a single LM guide was placed at the top center of the beam. All the LM guides were immediately supported on an aluminum base, which were then attached to the beam as shown in figure 2. Two base plates with cross-section of 300 mm length 200 mm width and 10 mm thick were attached on the lower part of the beam for the support. The beams were made of unidirectional and woven laminated CFRP with the wall thicknesses of 8mm to 12mm with 2mm variation.

2.1 Material Properties

Laminated composite structures are usually manufactured from unidirectional and woven plies of a given thickness. The main beam structure is made up of unidirectional and woven CFRP plies while the LM guide and supports are made of structural steel and the carriage is made of aluminum. The material properties of unidirectional, woven CFRP and structural steel are shown in table 2, table 3 and table 4 respectively.

Table 2. Unidirectional CFRP Material Properties

Elastic modulus (MPa)		Poisson's ratio	
Ex	110400	PRXY	0.3210
Ey	8403	PRYZ	0.0244
Ez	8403	PRXZ	0.3210
Shear modulus (MPa)		C. of Thermal Expansion (mm/mm℃)	
GXY	41787	ALPX	-3.50523E-06
GYZ	4101	ALPY	35.3803E-06
GXZ	41787	ALPZ	35.3803E-06



(a) (b) (c) (d)

Fig. 1. Cross sections of models (a) M1, (b) M2 (c) M3 and (d) M4

Table 3. Unidirectional CFRP Material Properties

Elastic modulus (MPa)	Poisson's ratio

Ex	81200	PRXY	0.3510
Ey	81200	PRYZ	0.0501
Ez	11600	PRXZ	0.0501
Shear modulus (MPa)		C. of Thermal Expansion (mm/mm °C)	
GXY	30052	ALPX	-1.540E-06
GYZ	5523	ALPY	-1.540E-06
GXZ	5523	ALPZ	35.380E-06

Table 4. Material properties of structural steel

Structural Steel	
Young's Modulus	2×105 MPa
Poisson's Ratio	0.3
Density	7.85e-006 kg/mm ³
Thermal Expansion	1.2e-005 1/℃
Tensile Yield Strength	250. MPa
Compressive Yield Strength	250. MPa
Tensile Ultimate Strength	460. MPa

3. Finite element model

3.1 Boundary Conditions

Optical module weighing 150kg rests on the carriage. Mass of the optical module was replaced by equivalent forces for the analysis. Forces of 750N each were applied on the top and the side of the carriage as shown in the figure 2.

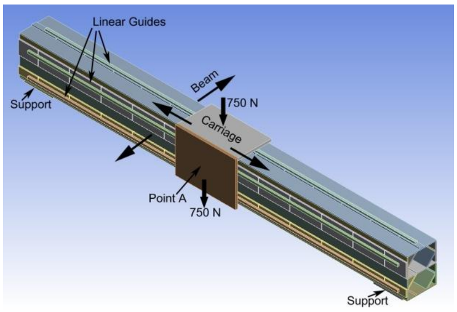


Fig. 2. Gantry stage system showing the carriage and LM guides

There are two movements in the assembled beam. Firstly, the assembled beam moves horizontally independent of the carriage movement. Secondly, the carriage moves along the length of the beam. When the beam travels horizontally with the acceleration of 1G, horizontal forces come into action which equals to the vertical forces in magnitude and act in the direction opposite to the movement of the beam (not shown in the figure). The supports at each ends of the beam were fixed. To accurately resemble the working condition, a gravitational force (g= 9.81m/sec^2) was applied vertically downward.

3.2 Laminate sequence

The unidirectional and woven lamina thicknesses were 0.15mm and 0.25mm respectively. Figure 3 shows the symmetric laminate (hereafter referred to as SYMM) used in this study, coordinates for the laminate and the details of wall thickness.

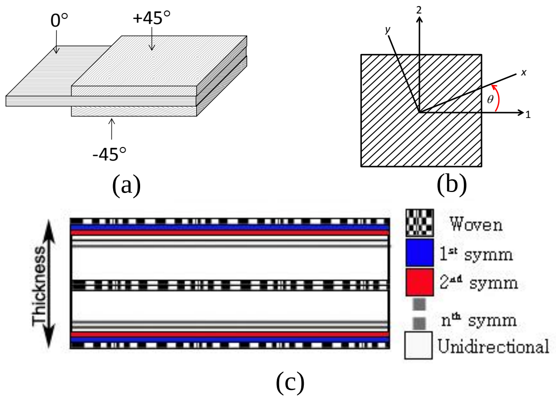


Fig. 3. Schematic lay-up sequence of (a) single symmetric angle-ply laminates (SYMM) (b) Laminate and ply coordinates and (c) a symmetric the beam wall

Two symmetry lay-up sequences; 45°/0°/-45° and 90°/0°/-90° were analyzed. A detail parametric layup sequence of the upper half of wall thickness is shown below.

Woven	Woven	Woven	Woven
SYMM	**SYMM**	**SYMM**	**SYMM**
0	**SYMM**	**SYMM**	**SYMM**
0	**SYMM**	**SYMM**	**SYMM**
0	0	**SYMM**	**SYMM**
0	0	**SYMM**	**SYMM**
0	0	0	**SYMM**
0	0	0	**SYMM**
0	0	0	0
Woven	Woven	Woven	Woven
(a)	(b)	(c)	(d)

Fig. 4. The parametric layup sequence for the numerical analysis

In figure 4, thickness between top & bottom woven ply is 1/2 of beam wall thickness. A total of 4 different laminates were used. A general purpose commercial software package ANSYS was used for the analysis [6]. A full finite element M3 model is shown in figure 5. In the analysis all the contacts were bonded and were restrained to slip against one another. 3D 20 node SOLID 186 with layered properties were used for the analysis. Nodes and elements for the analysis ranged from 70000 to 90000 and 10000 to 14000 for different models.

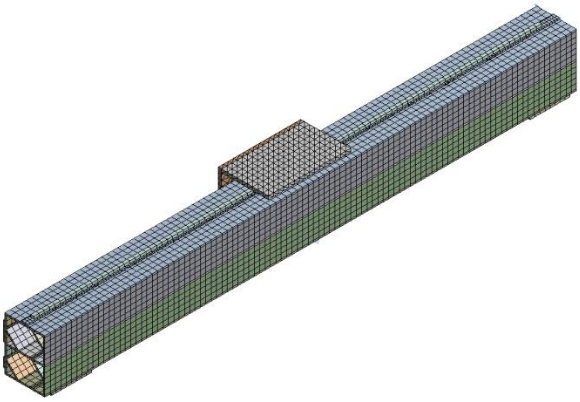


Fig. 5. FE mesh of M3 beam

4. Result and discussion

4.1 Finite Element analysis result

The deformation results were measured at the point, -85mm (x-axis), 200 mm (y-axis) and 2000mm (z-axis) (mid span of the beam) which lies at the center of the carriage. The deflections of the beam under loading conditions were measured relative to the un-deformed beam. Table 6, table 7 and table 8 lists the numerical solution of total deformation of all the four beam cross section with three different thicknesses (8mm, 10 mm and 12 mm).

Table 6. Static total deformation in 8 mm wall thick M3 beam for (45°/0°/-45°) type layup

Model	Total- deformation			
	1 symm	3 symm	5 symm	7 symm
M1	0.1439	0.1240	0.1169	0.1151
M2	0.0403	0.0370	0.0363	0.0365
M3	0.0305	0.0305	0.0312	0.0320
M4	0.0349	0.0352	0.0356	0.0360

Table 7. Static total deformation in 10 mm wall thick M3 beam for (45°/0°/-45°) type layup

Model	Total- deformation			
	1 symm	3 symm	5 symm	7 symm
M1	0.1158	0.0976	0.0898	0.0875
M2	0.0579	0.0513	0.0490	0.0483
M3	0.03127	0.0306	0.030	0.0311
M4	0.0324	0.03245	0.0326	0.0328

Table 8. Static total deformation in 12 mm wall thick M3 beam for (45°/0°/-45°) type layup

Model	Total- deformation			
	1 symm	3 symm	5 symm	7 symm
M1	0.0886	0.0737	0.067	0.065
M2	0.0455	0.0407	0.0388	0.038
M3	0.0281	0.0275	0.027	0.027
M4	0.032	0.0324	0.0325	0.0328

4.2 Experimental verification

A M4 gantry beam of 10 mm thick wall thickness and 7 symm laminates was fabricated and experimentally tested in a temperature and humidity controlled environment. The environmental condition during testing were, temperature (20.8±0.1)°C and relative humidity (55±1)%. The testing equipments with details used are listed in the table 5. A cross-sectional view of the fabricated composite beam is shown in figure 6. It should be noted that the triangular rib inserted in the beam is rounded at the corner.

Fig 6: A cross-sectional view of the fabricated composite beam

Table 5. Experimental testing equipments descriptions

Description	Manufacturer	Model
Laser Interferometer	Agilent	5519B
Weight	Mettler	

The static loading was performed with 150 kg mass on the center of the beam. Excellent agreement between the measured data and the numerical results were found for designed boundary condition validating the design.

The maximum deflection at the center of the beam along the length (z-axis) in y-axis was found to be 35µm while the maximum deflection at the center of the beam along the length in x-axis was measured to be 30µm. Both of the test shows that the beam satisfies the design specifications.

Straightness and flatness of the beam were also experimentally tested with the loading conditions. Figure 7 shows experimental straightness result in length direction (z-axis) while figure 8 shows the straightness in x-direction.

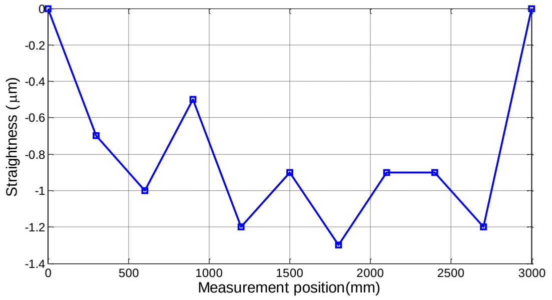


Fig. 7. Beam straightness along the length (z-axis) of the beam

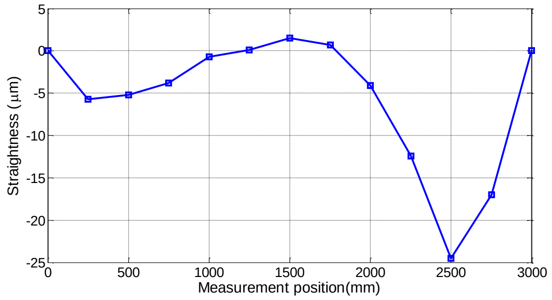


Fig. 8. Beam straightness along the breadth (x-axis) of the beam

Similarly, figure 9 shows the flatness on the vertical surface towards carriage on the z-axis, while figure 10 shows the flatness test result on the carriage in x-direction.

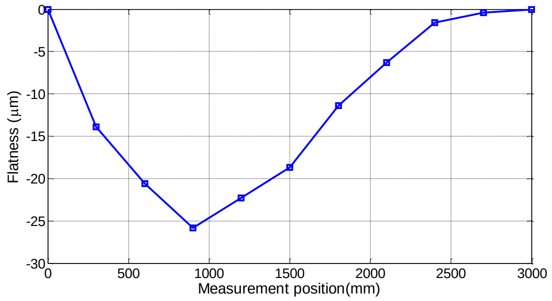


Fig. 9. Beam flatness along the length (z-axis) of the beam

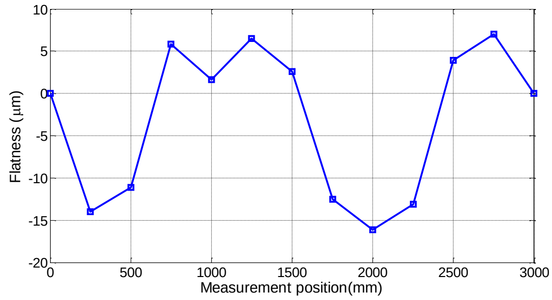


Fig. 10. Beam flatness along the breadth (x-axis) of the beam

It should be noted that the test for flatness and straightness of the carriage relative to the gantry beam is measured only for the operational length of 3000mm in the middle section of the beam.

It can be seen from the result that, the numerical solution of the beam matches well with the experimental test. The total deformation for M4 type beam with 10 mm thickness and 7 symm lay up sequence is 32 µm while the same beam when tested experimentally showed the maximum deflection of 35 µm.

4.3 Mass optimization of gantry beam

All the CFRP beam models were compared with corresponding aluminum beam models. In table 9, table 10 and table 11, weight comparison of aluminum and CFRP beams for 8 mm, 10 mm and 12 mm thick wall beam is shown, it can be seen that CFRP beams are lighter compared to aluminum beam. The weight reduction ranges from 16%~27%. The total deformation in case of M1 is highest among the beams, followed by M2, M4 and M3.

Table 9. Weight comparison of aluminum and CFRP beams (8mm)

Material of Beam	Weight (Kg)			
	M1	M2	M3	M4
Al	249	308	363	363
CFRP	196	229	266	307
Wt. ratio	0.786	0.743	0.731	0.846

Table 10. Weight comparison of aluminum and CFRP beams (10 mm)

Material of Beam	Weight (Kg)			
	M1	M2	M3	M4
Al	279	351	417	417
CFRP	212	253	290	348

Wt. ratio	0.759	0.720	0.690	0.834

Table 11. Weight comparison of aluminum and CFRP beams (12 mm)

Material of Beam	Weight (Kg)			
	M1	M2	M3	M4
Al	308	393	469	469
CFRP	229	276	319	386
Wt. ratio	0.743	0.702	0.643	0.823

The mass reduction ratio compared between CFRP and aluminum beams for the same cross-section and thickness are plotted in figure 11. It can be seen that with the increasing wall thickness of the beam the weight-ratio degreases almost linearly. However the slope of M3 beam is higher followed by M2, M1 and M4 respectively. The reason of low slope in case of M4 is due to the fact that it is reinforced by aluminum beam.

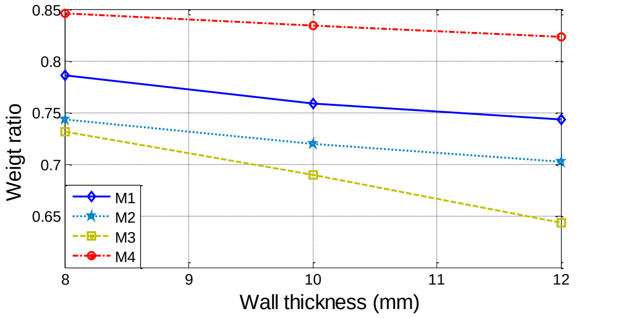


Fig. 11. Comparison of aluminum and CFRP gantry beam for various wall thicknesses

Conclusions

An optimized gantry beam for the LCD manufacturing was done by optimizing the weight and stiffness. The deformation was limited to 40μm. The parametrically designed and numerically analyzed beam was fabricated and tested. There was excellent match between numerical and experimental results.

Acknowledgement

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