Reliable and economical method to join optical tables

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Accepted for publication: 22 June 2011, Opt. Las. Eng. 49, 1251 - 1253 (2011)

Abstract

We present a practical method for joining pneumatically floated optical tables with no manufacturer preparation. We compare the stability of the joined table with one of its parts alone using Michelson Interferometry. We also compare the stability of two different pneumatic leg configurations in order to find the optimal one. We demonstrate that the joined table has comparable rigidity to its segments.

Keywords: optical table, joint, interferometric, stability

1. Introduction

The increasing complexity of optical experiments makes joined optical tables a common requirement for laboratories. Some examples are large laser based particle accelerators[1], charged particle bunch diagnostics[2], non-linear microscopy[3] setups etcetera. Various manufacturers of optical tables offer custom-prepared tables ready to be joined; however, it is not convenient or possible to expand existing unprepared tables given that they have to be re-engineered by the manufacturer in order to be joined. In addition, prepared table segments significantly exceed the price of similar unprepared tables. A prepared table has a cost about 25% higher than that of an unprepared table. Therefore an inexpensive and straight forward method for joining unprepared tables is desirable.

In Ref.[4] a method to join optical tables was presented, and Michelson interferometry[5, 6] was used to asses its rigidity. Yet important aspects such as the effect of a significant weight load or the pneumatic leg configuration were not discussed. In this work we present a method for joining existing optical tables with no previous preparation. We joined two tables (3000 mm×1500 mm×310 mm, Thorlabs PTR 52514; and 3750 mm×1500 mm×310 mm, Thorlabs PTR 52515) in an uncentered “T”-shape (offset by 325 mm, see Fig.1) and assessed, using Michelson interferometry, the rigidity of the junction when applying mechanical stress on the table. We compared the behaviour of the joined table for two different master-slave pneumatic leg (Thorlabs PTS 603) configurations in order to find the optimal one. We also compared interferometric measurements taken from only one segment of the joined table to an analogous test on an identical unjoined table (Thorlabs PTR 52514). Although our particular needs led us to the “T”-shape configuration described before the results presented here are expected to remain valid for other configurations.

2. Material and methods

The junction was made using twenty four stainless steel plates (SSP) machined as shown in Fig.1, this allowed distributing the stress across an extended area and a large number of screws. Twelve of them where evenly fixed to the top of the table across the joint using the M6 holes on the surface. The remaining twelve were evenly fixed across the bottom surface of the table by drilling and tapping M6 holes on it. A key point when assembling the joint was to press the two table segments against each other while the tables were floating. This way the bending and linear stress of the entire structure falls on the edges of the tables, this reduces the role of the SSPs to keeping the two table segments pressed against each other and prevents the plates from absorbing most of the stress. After assembling, the tables were unfloated in order to relax the pneumatic leg system and subsequently floated again.

Given that three independent points define a plane, the pneumatic insulation leg system of an optical table requires three master legs equipped with active height sensors and a number of passive slave legs driven by one of the master legs each. A T-shaped table such as the one described before requires eight legs in total as shown in Fig.1. On direct consultation with the table manufacturer we were recommended to avoid connecting slave legs under one table section with a master under the other section. The recommended configuration is shown in Fig.2 (i) and will be referred to as configuration A. Yet it is generally accepted that the master-slave configuration is decided by geometrical closeness, in other words, passive legs are slaves of the master closest to their position. Therefore, we decided to also try configuration B shown in Fig.2(ii).

3. Calculation

A relatively simple 2-dimensional static analysis was made in order to estimate which of the two configurations produces

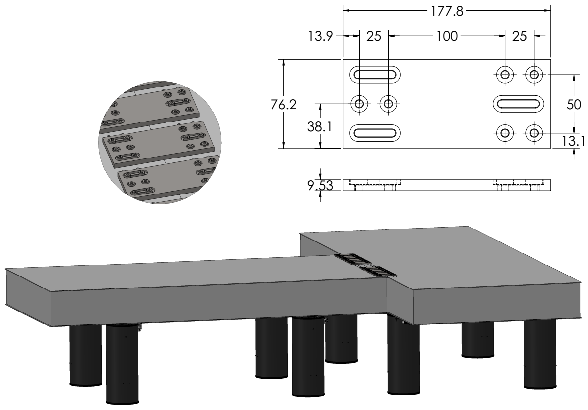

Figure 1: Three dimensional representation of the joined optical table. The circular inset shows a detailed view of the mounted stainless-steel plates used for the joint, which can be seen on the main figure. The dimensions of the plates are shown on the top right corner (in mm).

the least stress on the joint. In equilibrium, the forces of the legs connected to a single master are equal, and the total torque produced by the weight and the forces of the legs in two orthogonal directions in a plane parallel to the table is zero, therefore for configuration A

$$\begin{pmatrix} 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ x_1 & x_2 & x_3 & x_4 & x_5 & x_6 & x_7 & x_8 \\ y_1 & y_2 & y_3 & y_4 & y_5 & y_6 & y_7 & y_8 \end{pmatrix} \begin{pmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \\ F_5 \\ F_6 \\ F_7 \\ F_8 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ mg \\ \tau_y \\ \tau_x \end{pmatrix},$$

where F_i is the force on the i-th leg located at (x_i, y_i), m is the total mass of the table top, g is 9.81 m/s^2 and τ_x and τ_y are the torques produced by the table weight on the x and y axes which is calculated numerically using a fine grid (1 mm per side) of the "T"-shaped mass distribution. For configuration B we obtain an analogous system given by

$$\begin{pmatrix} 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ x_1 & x_2 & x_3 & x_4 & x_5 & x_6 & x_7 & x_8 \\ y_1 & y_2 & y_3 & y_4 & y_5 & y_6 & y_7 & y_8 \end{pmatrix} \begin{pmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \\ F_5 \\ F_6 \\ F_7 \\ F_8 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ mg \\ \tau_y \\ \tau_x \end{pmatrix}.$$

By resolving the two systems we obtain the forces on each leg, from them it is possible to calculate the partial torque applied on each side of the joint that will give us a measure of which configuration produces a greater stress on the joint. These partial torques turn out to be 20763 Nm and 20428 Nm for configurations A and B respectively, showing a difference of 335 Nm (∼1.6%). This calculation suggests that configuration B produces smaller stress on the joint than configuration A.

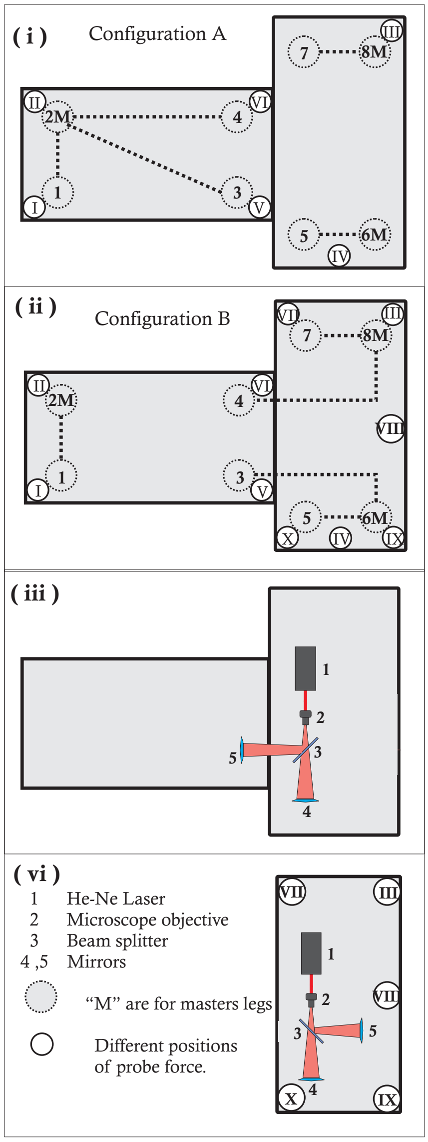

Figure 2: (i) Configuration A of master (M) and slave legs and positions (in Roman numerals) over which the probe force was applied in the first comparison. (ii) Configuration B of master (M) and slave legs and positions (in Roman numerals) over which the probe force was applied in the first and second comparisons. The dashed lines represent the pneumatic connections between the master and slave legs. (iii) Michelson interferometer on a system of coupled optical tables with an arm passing trough the joint. (iv) Michelson interferometer on a single table and positions over which the probe force was applied.

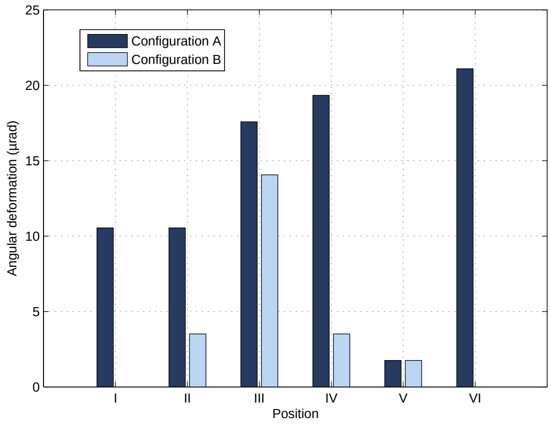

Figure 3: Deformation angle in microradians measured by the interferometer when applying weight at each position in both leg configurations; configuration suggested by the manufacturer (Configuration A) and an alternative configuration (Configuration B).

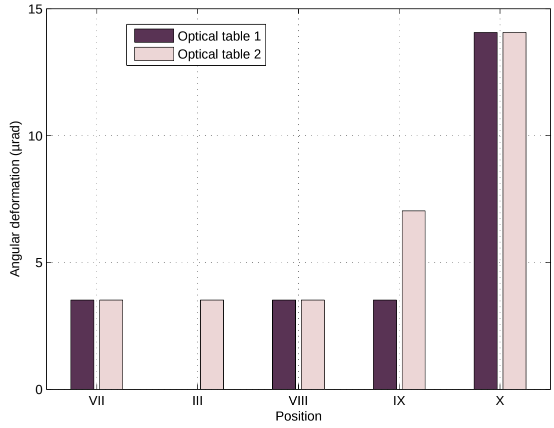

Figure 4: Deformation angle in microradians measured by the interferometer when applying a weight at each position in a single optical table (Optical table 1) and in a system of coupled optical tables (Optical table 2).

4. Results

The rigidity of the joint was measured using Michelson interferometry and applying a weight of 745 N on the positions labeled I to X on Fig.2. This weight is significantly larger than typical localized loads applied to optical tables under normal circumstances. These positions are well distributed around the table near the edge where they are expected to produce larger torques on the joint. The interferometer was set up using a HeNe laser at a wavelength of $\lambda = 632.8$ nm, which was focused by a 20 X microscope objective. One arm of the interferometer was set across the joint and another arm on one of the segments as shown on Fig.2 (iii). The deformation caused by the weight was quantified by counting interference fringes, the number of fringes N was subsequently used to calculate the deflection angle of the table

$$\theta = \arctan\frac{N \cdot \lambda}{h_b}$$

where h_b is the beam's height measured from the table surface. Given that he measurement was done by counting fringes the associate uncertainty would be a full fringe which is equivalent to $\delta\theta \approx 3.5\,\mu$rad.

A set of measurements was performed for each of the two pneumatic leg configurations described earlier. Each independent measurement was performed three times to confirm repeatability. The deformation angles are presented on Fig.3 as a function of the location of the applied force. Firstly it is important to notice that even in the worst case (configuration A, position VI) deformation was rather small ($\sim 20\,\mu$rad or ~ 4 arcsec), and that this deformation occurred on the application of an unusually large stress for everyday use (745 N). Secondly it is interesting to see that the deformation was greater or equal on all positions for configuration A than on configuration B. Therefore for further measurements we will choose configuration B.

Two additional sets of measurements were performed in order to assess if the joint affects the mechanical behaviour of the table segments. Firstly the Michelson interferometer was repositioned entirely on one of the segments forming the "T", subsequently stress was applied at the positions shown in Fig.2iv. Secondly, in order to compare the behaviour of the joined table and its segments alone, the interferometer was moved to an identical unjoined table segment and located on an equivalent position as depicted in Fig.2iv. The deflections measured with the interferometer are shown in Fig.4. Interestingly the deformations are equal within the uncertainty of the measurement for both cases demonstrating that the stress of the joint does not significantly affect the mechanical stability of the segments.

5. Conclusions

In conclusion, we presented a method for joining optical tables using SSPs. The plates require using two rows of threaded holes on each table segment for the joint. We demonstrated that the mechanical stability of the joined table is comparable to that of its component segments. We also showed that the appropriate choice of master-slave leg configuration results in smaller deflection of the table. This method is significantly cheaper than the segment preparation offered by table manufacturers, and has the additional advantage that can easily be implemented to add table segments already in use.

6. Acknowledgements

The authors would like to thank CONACyT (Mexico) for financial support [Grant no. 126736] and for Scholarships [no. 235260, 235247 and 349278].

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