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DESIGN OF PARTICLE IMAGE VELOCIMETRY SYSTEM FOR THE WIND TUNNEL OF UNIVERSITY OF ŽILINA

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Abstract

Due to always ongoing innovation in research ability of our research facility it was decided to innovate already existing wind tunnel by implementing system of Particle Image Velocimetry. Main goal of this thesis is to create sufficient technical solution for implementation of Particle Image Velocimetry measuring systems. This system will allow creation of accurate measurements of aerodynamic forces and visualise airflow direction and its strength. Implementation of this system consists of designing sufficient structure to allow proper mount and movement of laser light source, which will be high power laser and mount for camera, which will be used to capture images of airflow of measured parts. In terms of laser stand, the main goal was to simplify the construction to decrease costs of structure and to create room for future upgrades and implementations of possible motorisation and electronic controls. For main construction were chosen steel profiles with square cut and size of 30x30 mm to match already existing construction used to stabilise measured part in test chamber. Implementation of this system of measurement will increase research abilities and it will create room for more projects, which depend on this method of measurement. Particle Image Velocimetry has wide range of usage from automotive industry through aviation to designing of spray nozzles. This will create large research opportunities for other facilities and professionals from different parts of industry, since this technology will be one of the first implemented into wind tunnel in Slovakia.

Keywords

PIV, Particle Image Velocimetry, PID, Aerodynamics

1. INTRODUCTION

Since mankind has longed to fly from ancient times, attempts have always been made to get man into the air so that he can soar freely like a bird. In order to find out the principle of flight of birds, engineers have tried to invent different ways of measuring the forces acting on them during flight. With these experiments came the first records of attempts to visualize the flow around bodies drawn by Leonardo Da Vinci. Further experiments led scientists to controllable spaces for experiments in aerodynamics. These spaces and objects are now known as wind tunnels. The first way of visualizing flow was and still is through the use of smoke. This method also persists mainly because of its effortlessness and simplicity. The invention of the light-emitting diode opened the way for new methods of measurement thanks to the possibility of concentrating this light into a single beam of high luminous intensity. The combination of these two methods gave rise to the measurement method now known as Integral Laser Anemometry. This relatively new technology finds its application in fields that deal with fluid flow around a body or flow directly through a body. The most widespread measurement set-ups are mainly used in water tunnel areas, or for research on the atomization efficiency of spray nozzles. This means that we will encounter problems and situations in the design process that occur exclusively in wind tunnel applications.

Since this measurement method relies on three main elements of the assembly, which are lighting, sensing and computation it is necessary to align these three elements to form a single unit in which these components are balanced. Good visibility of what is going on in the test chamber must be ensured by a suitable light source that is able to illuminate the space to such an extent as to allow seamless image capture. The image acquisition is the responsibility of the image acquisition equipment, which must ensure that the quality of the images is sufficient to allow calculations to be carried out on the basis of the images. The calculations are performed by software which allows a relatively fast and accurate evaluation of the captured image.

The aim of this research is to create a complete system that will be suitable for conducting research in the field of fluid flow, with the subsequent possibility of visualising the measured values, which can then be further processed according to the type of experiment.

2. MATERIALS AND METHODS

2.1. PIV technology

For our research we have chosen planar 2D method. This method will allow us to create basic computed measurements and visualisations with high precision of calculated results. 2D method was chosen also due to its lower cost in comparison with other methods and techniques. Since it is important for rig components like laser and camera to be fixed in place, so that they will not move during experiments and measurements it was necessary to design a rig, that will be capable of providing stability of components and their movability, which will allow us to set up the whole rig to or needs and into necessary position [1].

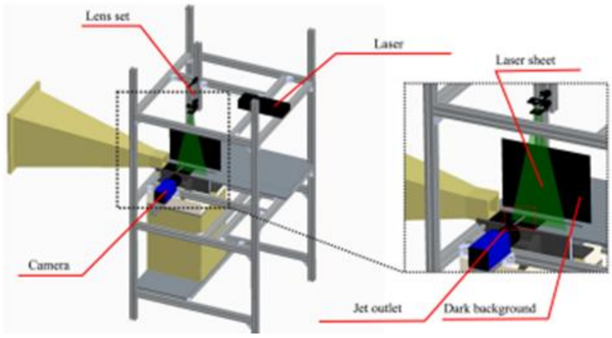

Figure 1: Description of 2D PIV rig [2]

2.2. Wind tunnel

The wind tunnel used for our research and implementation of PIV system is placed in the Research centre of University of Žilina. This tunnel is tunnel working with low speeds, and its maximum flow speed in test chamber is 100 km/h. Tunnel is in open air circulation configuration. Length of test chamber is 640 mm. This means, that reflective particles will travel through the test chamber in only 23 ms. Due to this speed and set number of frames of 90 for our experiment, it is necessary to use camera, that is capable of speeds as high as 4000 FPS. Due to this specification, it is necessary to pick the right research grade camera, since regular consumer cameras are not able of such speeds, and they are usually providing only around 60-120 FPS, which is too slow for the research needs [3]

2.3. Design of testing rig and component selection

Design has two parts. First part consists of laser mounting rig and second part is camera stative.

2.3.1. Design of laser mounting rig

Laser mounting rig has three separate parts. First fixed part is used for vertical element of the mounting mechanism. For this steel profiles with square cut and dimensions of 30 x 30 mm with wall thickness of 2 mm were used, to ensure size compatibility with already existing rig used for measuring aerodynamic forces, onto which this vertical element will be mounted.

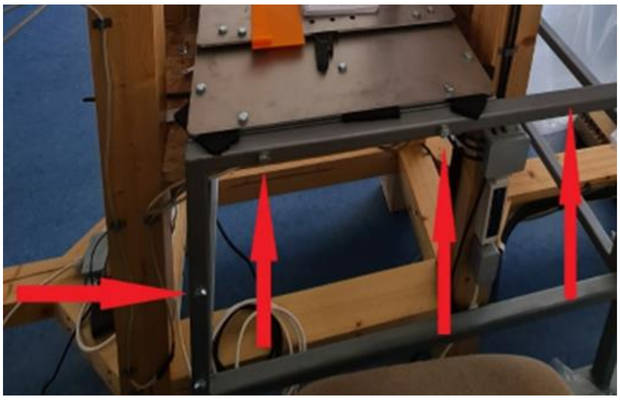

Figure 2: Testing rig with highlighted mounting areas of vertical element

For fixation of vertical element, three nut bolts with size of M10 x 110 mm and one M10 x 80 mm were d. To ensure ability to set testing height of mounted laser, use another steel profile with dimensions of 25 x 25 mm with length of 500 mm was used, to ensure possibility of vertical setting. This smaller profile is fitted into second part of vertical construction. Height of laser can be set in the span of 200 mm, and it can be fixed by usage of two M6 x 50 bolt screws in pre-drilled holes spaced by 20 mm. The same bolt screws are used to fix the smaller profile into the second part of vertical construction.

Horizontal movement is secured by T shaped rig. This rig has its fixed part, which us used for housing and securing of the T shaped rig. This rig consists of two steel profiles. One with dimensions of 20 x 20 mm and second one with 30 x 30 dimensions. Both profiles have square cut and 2 mm wall thickness. Movement of this rig is secured by 8 ball bearing balls with diameter of 5 mm. Due to use of these parts it was necessary to create groove in all four sides of the profile, thanks to which perfect alignment, fit and stability of both parts was ensured. The fixed part of horizontal construction is made using steel profiles of square cut and size 30 x 30 mm. For sideways move the smaller 20 x 20 mm is used. This ensured spacing big enough for usage of ball bearings of mentioned 5 mm diameter.

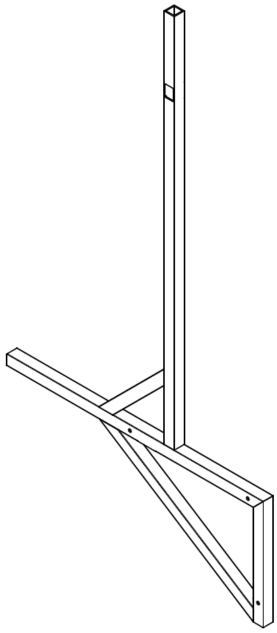

Figure 3: Design of vertical element of construction

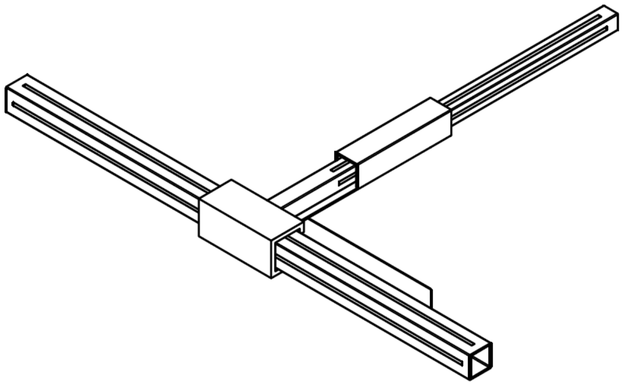

Figure 4: Design of horizontal construction

Horizontal construction can be fixed in set place by the usage of two M8 x 25 mm bolt screws. This size allows for area big enough to hold the rig in place and does not cut into groove for ball bearing balls. For lengthwise setting of the laser, 3D printed moving rig was designed, which has slide in mount for laser holder in its bottom part. Movement of this mount is also ensured by usage of six 5 mm steel ball bearing balls.

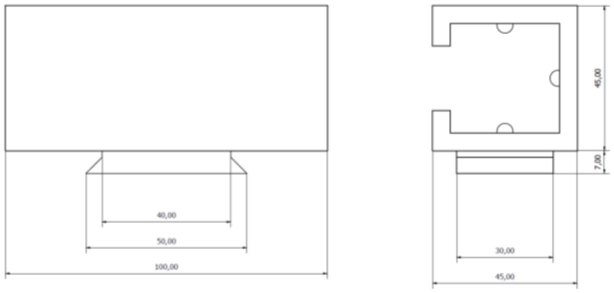

Figure 5: Design and sizing of laser holder rig

For mounting of laser, two-piece rig with ability to set angle of the laser was designed. First part has cut out for mounting onto laser mounter rig. These two parts are then fixed in place using M4 x 10 bolt screw.

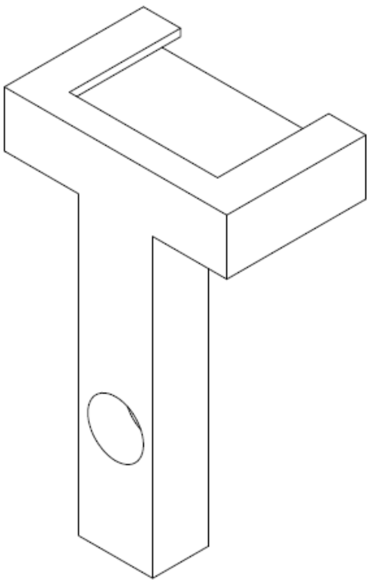

Figure 6: Design of fixed part of laser holder

To ensure setting of angle, this part has circular cut out with diameter 15 mm. This cut out has also hole for a fixing screw with diameter of 4 mm.

Second part of this laser holder consists of laser holder itself, which contains 10 mm extrusion with diameter of 15 mm. This ensures perfect fit and ability to set angle of the laser. Inner part of this holder has the same dimensions as laser, which are 33 x 33 mm. Bottom part of the holder has hole for M4 screw, which is used to tighten the fit for laser.

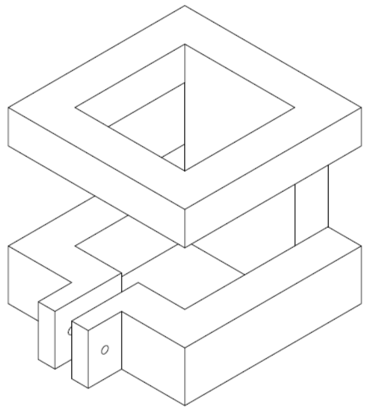

Figure 7: Design of rotational part of the laser holder

2.3.2. <u>Choice of light source</u>

Since we will use PIV in the wind tunnel with open air circulation, it was necessary, to choose laser, which will be bright and powerful enough to be visible in the daylight and in bright environment.

For our use we have chosen 400 mW laser with wavelength of 520 nm, which means, that the laser beam has bright green color. This laser is equipped with line optics, which means, that there is no need for optics, that would be normally used to change the collimated beam of light into line beam. This laser is capable of creating light line with angle of 110°. Thanks to this, smaller height over the test chamber is needed. This means, that the laser will not loose its power due to high height over the test chamber, which would be present in case of steeper beam angle.

Cooling of laser is passive, which ensures proper cooling of the unit. In case of high temperatures in the test facility, there is possibility of mounting cooling fan, which will help with cooling of the laser unit.

Laser is powered with 12 V DC power, which is converted using 220 V AC adapter.

2.3.3. <u>Choice of camera</u>

As it was mentioned earlier, camera, which will be used for high-speed capture has to be capable of capturing at rate of at least 4000 FPS. Due to this requirement, we have chosen the Mega Speed MS90K-SC camera, which has maximum framerate of 270 000 FPS. Camera is capable of resolution 1280 x 800 at 4000 FPS, which provides us with area big enough to conduct experiments. In case of upgrade of the tunnel high speed, there is still big enough reserve of possible usable framerate. For our use of flow rate in the test section of up to 100 km/h table of suggested minimum FPS for selected speed was created.

Table 1: Recommended minimum framerate based on flow speed

km/h	**FPS**	**km/h**	**FPS**	**km/h**	**FPS**
100	4000	67	3000	35	1500
99	4000	66	3000	33	1500
98	4000	65	3000	32	1500
97	4000	64	3000	31	1500

96	4000	63	3000	30	1500
95	4000	62	2000	29	1500
94	4000	61	2000	28	1500
93	4000	60	2000	27	1500
92	4000	59	2000	26	1500
91	4000	58	2000	25	1000
90	4000	57	2000	24	1000
89	4000	56	2000	23	1000
88	4000	55	2000	22	1000
87	4000	54	2000	21	1000
86	4000	53	2000	20	1000
85	4000	52	2000	19	1000
84	4000	51	2000	18	750
83	3000	34	1500	17	750
82	3000	50	2000	16	750
81	3000	49	2000	15	750
80	3000	48	2000	14	750
79	3000	47	2000	13	750
78	3000	46	2000	12	500
77	3000	45	2000	11	500
76	3000	44	2000	10	500
75	3000	43	2000	9	500
74	3000	42	2000	8	350
73	3000	41	2000	7	350
72	3000	40	1500	6	350
71	3000	39	1500	5	250
70	3000	38	1500	4	250
69	3000	37	1500	3	180
68	3000	36	1500	2	125
				1	45

2.3.4. Choice of computer

Since we are using for computation and visualization MatLab software with plugin PIVlab, the only requirement is minimum of 8 GB of RAM and SSD memory drive, which will ensure quick processing of captured images. We have chosen MatLab with PIVlab extension due to its user-friendly environment and simplicity. This software has also all the necessary features needed for conducting experiments in 2D PIV settings.

3. RESULTS

After considering all of the mentioned components of design and rig parts, we were able to create and calculate pricing list of all necessary components needed for completion of this testing rig. All components are listened in table below with their prices.

Table 2: List of components and material with their specific prices

Component	Amount	Prince in €
21,5" AOC E2270SWDN	1	123,90
Acer Aspire TC-1760	1	610,90
CAT6 UTP Patch Cord Cable	2 m	4,00
C-TECH KBM-102	1	7,30
Circular washer 10,5 x 20 mm	1	0,10
Circular washer 10,5 x 30 mm	3	0,50
Mega Speed MS90K-SC	1	2 400,00
MZTech Green laser module with cooling	1	295,00
Steel profile 20 x 20 mm	1 m	4,90
Steel profile 25 x 25 mm	0,5 m	2,34
Steel profile 30 x 30 mm	4,5 m	22,50
Protective glasses for green laser	3	45,00
Bolt screw M10 x 110 mm	3	1,30
Bolt screw M10 x 80 mm	1	0,40
Nut M10	4	0,25
Nozzle 1/4-M2	1	12,00
Total estimated price		3 530,39

Construction of the test rig had already begun, but came to a stop due to issues with sourcing of laser unit, due to which it was not possible to properly calibrate testing rig and demonstrate capabilities of flow computation and visualisation.

4. CONCLUSION

Due to always ongoing modernisation of wind tunnel in research facility it was only matter of time, when would this modern technology of flow measurement. Thanks to this research and design of testing rig it is possible to implement 2D PIV system, with possibility of further extension for stereoscopic or 3D methods. After obtaining selected laser in the near future, it will be possible to create measurements and visualisations of flow using selected software. While designing testing rig, the idea was to create simple but effective construction, in which task we have succeeded. Thanks to this design decision we have managed to keep the cost of materials low.

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