Design and Manufacturing of Anemometer for Hot Gases from available Cheap Materials

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Abstract: -

This work is to build anemometer, especially for hot air or hot gas flow, from a very cheap materials available as a waste in reforming shops and small factories. The design of this tool takes in to account that any primitive technician or smith can build the tool. At the beginning, the parts of tool are designed using Catia V5R17 Software and some parts are imported to ANSYS WORKBENCH 2020 R2 software for test of mechanical stresses and deformation associated with temperature increment. Then, theoretical computations are made where angular displacement is calculated, based on equations solved by MATLAB R2020a software, where the tool faces flow air streams with different speed magnitudes. Those different air speed magnitudes used in the experiment are 1 m/s, 1.5 m/s, 2 m/s, 2.5 m/s, 3 m/s, 3.5 m/s, and 4 m/s. After that, a real tool is built and be placed in duct having a dimensions of 2 m length, 0.35m height and 0.3m width. The air flowing in that duct has the same different speed magnitudes used in theoretical computations. Then, comparison between the two results is made, which show that despite there is a relatively slide difference in angular displacement readings but the response of the real tool to the different air speed magnitudes are very coincides with the theoretical.

Keywords: Angular displacement, Gas flow speed, Deformation, Thermal stresses, Moments, Friction, Reaction force

Introduction: -

This paper is another step to build a fully automatic controlled air conditioning (HVAC) and heating system. An Anemometer is a tool to measure the speed of air or gas. The measurement can be done directly either in contained flow, such as flow in duct, or unconfined flow such as the form of wind [1]. There are several types of anemometers like cup type, vane type, hot wire type anemometer, laser Doppler type, ultrasonic type, windmill type, pressure type and ping-pong ball type anemometer [2]. Most of these anemometers are only working at room temperature and some of them, like laser doppler and ultrasonic, can work within high temperature range. The laser doppler anemometer requires emitter for laser beams and a receiver. It works on principle of measuring time rate change of laser frequency for gas' particles intersected by the laser beams [3]. The ultrasonic anemometer works on principle that the flow of gas will change the ultrasonic wave propagation passing through and that change is proportional

to the speed or flow rate of gas. By measuring the time rate of ultrasonic wave propagation, the speed of gas is computed [4].

Therefore, based on former explanation, the laser and ultrasonic anemometers are hard to be built by hand. Also, those anemometers are expensive and rarely available in markets. They are widely used in industry and are bought directly from their manufacturing. In Iraq, it is very hard to get such tool as well as it is economically unworthy to spend much money for an auxiliary design. Therefore, an alternative tool should be built to replace the professional one.

First, to build the tool, one can use the manometer methodology which depends on the height of liquid level as indication of hot gases speed [5]. Despite manometer can give acceptable precise results but it is not portable and it should be permanently mounted on duct in which the speed of hot gases is measured. Second, a cup type anemometer methodology can be used to build the tool for hot gases [6]. Also, a digital electronic control can be added to the design, based on this methodology, to compute the speed of cups' rotation [7]. But, the big size of cups and their equipment will be obstacle to be used in ducts and narrow places. Besides, the handmade process for building this form will be rather difficult and not accurate enough [8]. Third, the principle of hot wire type anemometer methodology can be used. This principle is based on the measuring of the change in resistance of wire, placed in gas' streams, in which an electric current pass. Due to heat transfer from wire to gas stream, the electric wire cooled and resistance will decrease. This type requires clean gas as well as high electrical current directly proportional to the gas temperature [9]. So, it will be hard to build such tool even by professional engineers. Therefore, an independent thought should be followed to build this special type of anemometer based on what available in hand. Gas's thrust principle can be followed to build this tool as it will be shown down.

Parts of the tool:

The only material used to build the tool is an aluminum to avoid the rust generated from humidity and high temperature in gas besides aluminum is a light metal which minimizes the inertia. The steps of designing this tool should consider the thermal strength of its parts, range of working, and the environment of working. The tool generally consists of two main parts, the paddle and the holder or frame. The dimensions of these parts are selected to be suitable for using the tool inside or outside the ducts with enough accurate results. The parts of switch are:

1. The paddle, shown in Figure.1 below, has a rectangular shape and its upper side is formed in such a way that it is pinned with the holder or frame. It works to let gas move it around the pin. The thickness of its aluminum plate is 0.9 mm. Figure 1 below shows the dimension of the paddle.
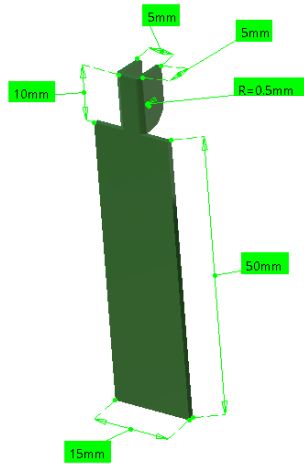
Paddle in Catia V5R17   **Real paddle**

Fig (1) Paddle part in reality and in Catia Software

Note: The paddle is drawn by CATIA V5R17 software and is built in reality as shown in Figure 1 above

2. The second part is the holder or frame. The frame is 100 mm diameter cylinder with a 100 mm length. It is made by rolling a 0.9 mm thickness aluminum plate. This part has a region formed in such a way that holder is pinned at and move around as shown in Figure 2 below. Also, it carries the scale of speed readings as it will be discussed later. Figure 2 below shows this part in Catia V5R17 software and in reality.
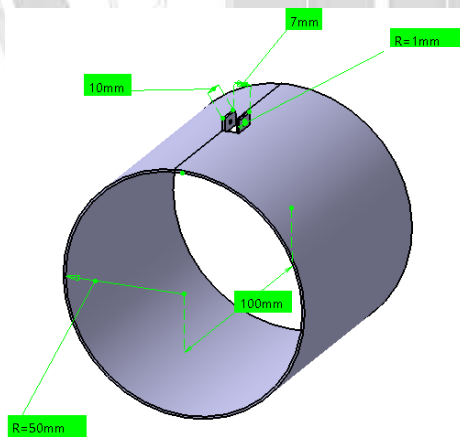
Frame in Catia with all dimension   **Real frame picture**

Figure. 2 The Frame in reality and in Catia Software

Also, there are additional auxiliary parts added to the whole real tool as shown in Figure 3 B and C below; those parts are for reading the speed and for holding the tool. The axillary parts are: - aluminum plate, mounted on the frame, together with an indicator and the hanging wires for holding the tool.

A- Whole tool in Catia   B- Whole real tool   C- Side view of real tool

Figure 3 Whole tool in reality and in Catia Software

Tool's work:

The paddle faces streams of hot gases and when those streams have enough power, it will push the paddle away at angular distance proportional to the flow rate of the gas. The cylindrical shape of the holder or frame helps to organize the streams of flow. The magnitudes of speeds are radially written on auxiliary plate part. The indicator is an aluminum needle glued at the top of the paddle and moves together with paddle to refer the magnitude of the speed on the auxiliary plate

Building the tool: -

Before building the tool in reality, there is a need to do theoretical calculations to check the model and to estimate all problems that might be appear during the operation.

Theoretical calculation: -

This tool is subjected to heat during operation; therefore, thermal stresses will be induced which might effect on readings within operation. In the frame, particularly the cylinder, the shape of cylinder helps minimizing the thermal stresses; therefore, the holder part will not be checked for thermal stresses [10]. But regions of the holder or frame, where the paddle is pinned with, might have noticeable thermal deformation which minimize the thermal stresses on the paddle because both upper side of paddle and segment of holder, pinned to the paddle, will thermally extend in the same direction. The segment of the paddle, where it is pinned with frame, will have the most stresses and those stresses will cause mechanical pressure at the same region. That pressure causes restriction, resulting in friction, to rotate the paddle around the pin.

Therefore, this case should be checked before designing the real part.   A mathematical model is made to compute those stresses using ANSYS WORKBENCH 2020 software. Under worst thermal deformation conditions, it will be assumed that there is no thermal deformation in frame part, including the region where paddle is in contact, and only a thermal deformation in paddle will be considered i.e., zero-thermal deformation is assumed in the frame only.

Based on assumptions above, a mesh is defined as shown in Figure 4D in the paddle with different element size, depending on load and stress concentration in the part, and a tetrahedrane element type is used with about 18360 elements [11]. Also, in the paddle part, a zero-displacement boundary condition is applied in x-direction at the surfaces contacting the holder part as shown in Figure 4a below. Besides, a cylindrical support is defined at inner surfaces of the holes, where pin is in contact with, to represent the joint as shown in Figure 4b. As well as a thermal load of 200 °C is applied as a unit step to whole paddle part as a result of exposure the whole body to a uniform heat during working.

A- Zero displacement   B.C   **B- Cylindrical Support B.C.**

**C- whole boundary conditions**   **D- meshing of the paddle**
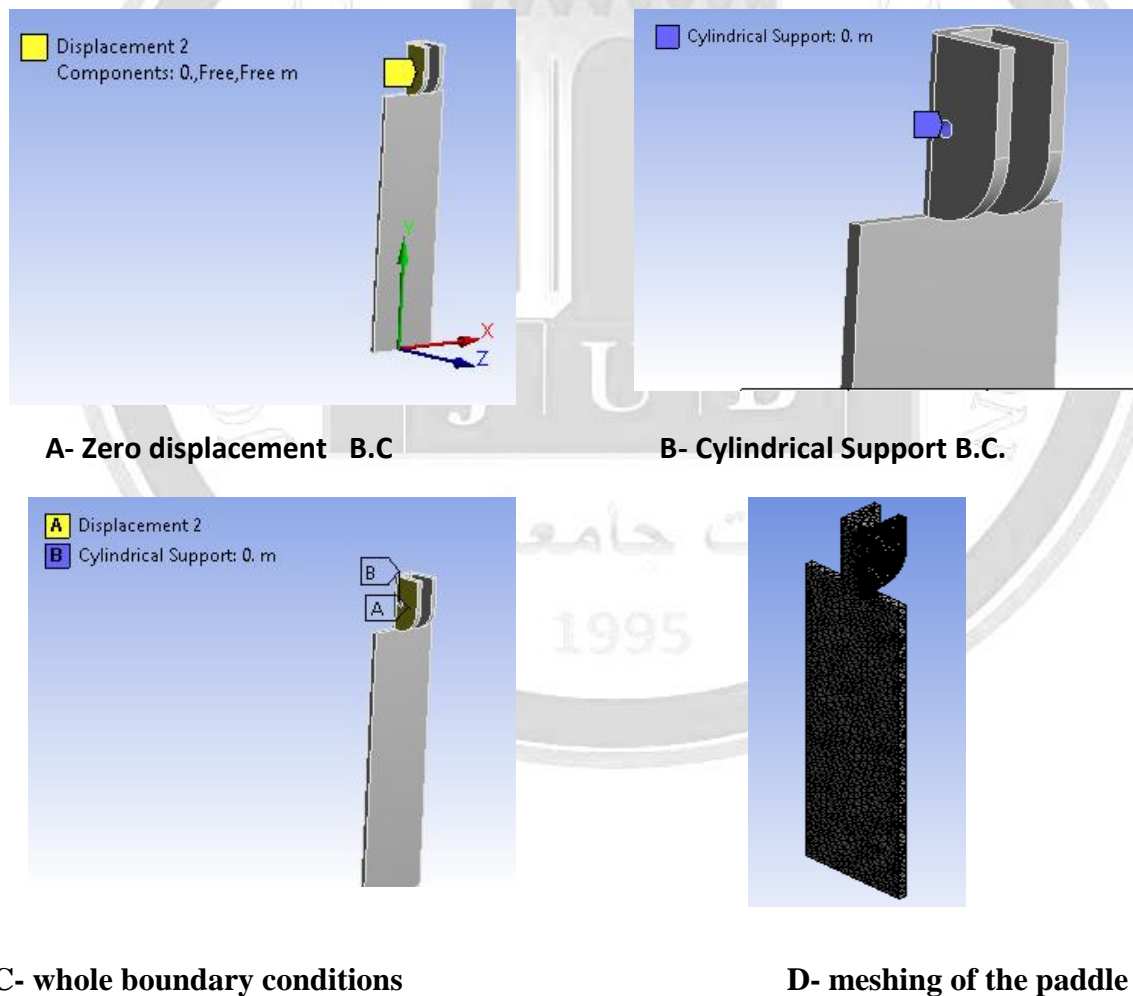
**Figure 4 Boundary Conditions and Meshing**

After that the model is solved and Figure 5 below shows the obtained results. Figure 5A shows the reaction force on the faces of the paddle, where they will contact with frame, is about 42 MN and this force will cause huge friction force which will eventually restrict the angular motion of the paddle. Also, the maximum von messes stress is at the neck of the paddle as shown in Figure 5B. The max. amount of that stress is 745 MPa, which is far above the yield strength of the aluminum (276 MPa), and will cause a plastic deformation in the paddle [12]. Therefore, a tolerance or clearness should be placed between paddle and frame i.e., there will be no direct contact between the two parts. The amount of that clearness can be computed by removing the zero-displacement boundary condition on paddle and resolve the model again. After resolution, the maximum amount of the free directional deformation on the faces, which is near to be in contact with holder in reality, is about 0.022 mm as shown in Figure. 6 below.

Based on last result, a clearance of 0.1 mm, which is more than enough, is made between the parallel faces of paddle and holder in real design of the tool. It can be noted in Figure. 6 below, the minus signs in the result refers only to direction of the deformation with respect to the coordinates in the Workbench.
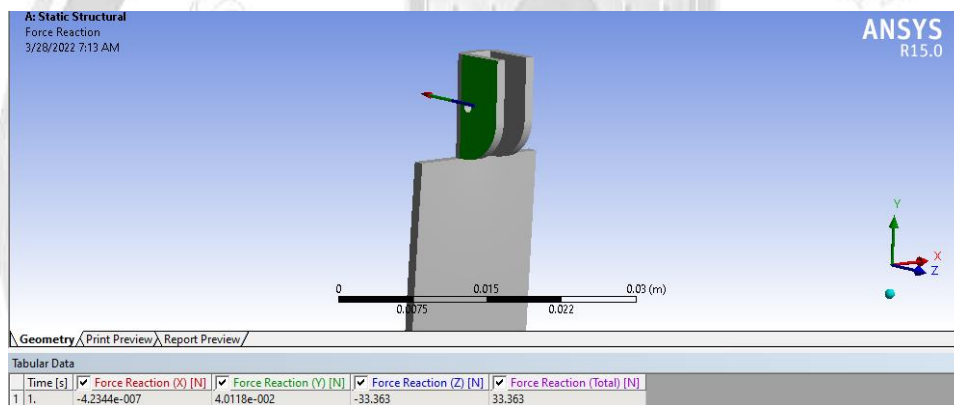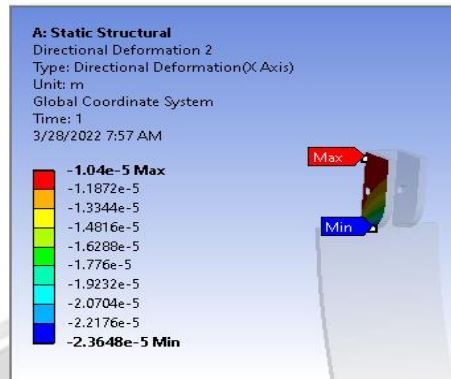

A- Rection force
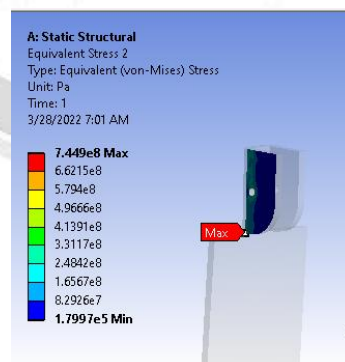
B. maximum von messes stress

Figure 5   Workbench preliminary Results

Figure 6 Free deformation of upper segment of paddle in Workbench

Motion of paddle's calculation:

To compute the angle made by the paddle with the vertical when enough powered air hits the paddle, the moment equilibrium equation is used where the moment resulting in the air's thrust is equal to the moment resulting in the weight of the paddle about the pin. Before applying the equation, several parameters require to be defined because those parameters will be used in equations and in MATLAB code. Those parameters are explained in details below and in Figure 7 as well.

Front view   **Side View**
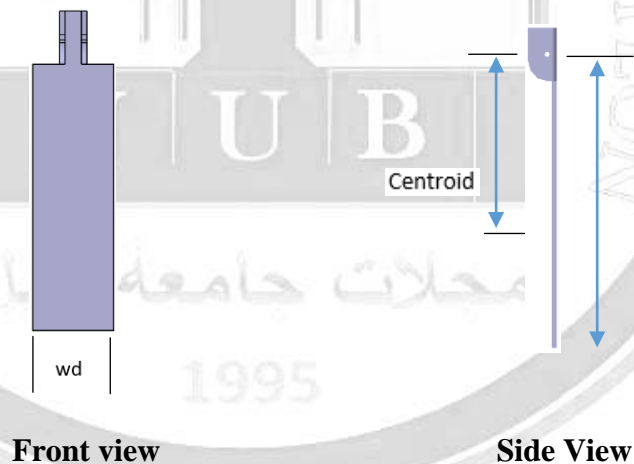
Figure 7 Front and side view of Paddle

d=10e-2   is the diameter of the cylinder
L=5e-2   is the length of the paddle from the pin
rou=1   is the density of air
v=2   is the speed of air
dens= 2710   is he density of aluminum
t= 0.001   is the thickness of paddle and frame's plate
wd=1.5e-2   is the width of paddle
Note: All units used above are in meter.

Therefore, based on model in the Figure 8:-
The gas' thrust force on paddle can be obtained by [13]:

```
f= rou*A*v{v-[v*sin(th)]}   --------  1
```

Where: -

f-   gas' thrust force on the paddle (N)
A-   area of paddle facing the gas (m^2)
v -   Speed of gas(m/Sec)
rou- density of gas(kg/m^3)
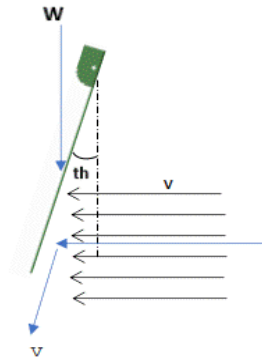th- angle between the paddle and the vertical (degree)

Figure 8 Air-Paddle Model

Now, the equilibrium of moment equation can be applied to the model: -

$$\sum \text{Moment about the pin} = \text{zero}$$

$$f * \left(\frac{L}{2}\right) * \cos(th) - w * \frac{L}{2} * \sin(th) = 0 \qquad\qquad 2$$

Where (w) is the weight of the paddle

Substituting the thrust equation (1) into moment equation (2), another equation is obtained:

$$rou*A*v\{v-[v*\sin(th)]\} * \left(\frac{L}{2}\right) * \cos(th) - w * \frac{L}{2} * \sin(th) = 0$$

The last equation cannot be solved for (th) term using conventional mathematic; therefore, trial and error method will be helpful for solution [14] and by using the MATLAB code, very accurate result will be obtained [15]. Figure 9 below shows the MATLAB code

Figure 9 MATLAB Code to compute an angle (th)

Seven different speed magnitudes in m/sec unit are selected in the MATLAB code to compute their corresponding angle's values and, as shown in Table 1 and Figure 10, the angle is proportional to the gas' speed.

Table 1 Relation between Air speed and Angle (th) in MATLAB

Air Speed	Angle in MATLAB	Error
1	15.2	0.0000001
1.5	25.4	0.0000001
2	33.5	0.0000001
2.5	39.7	0.00000013
3	44.6	0.00000013
3.5	48.5	0.000000175
4	51.7	0.000000175
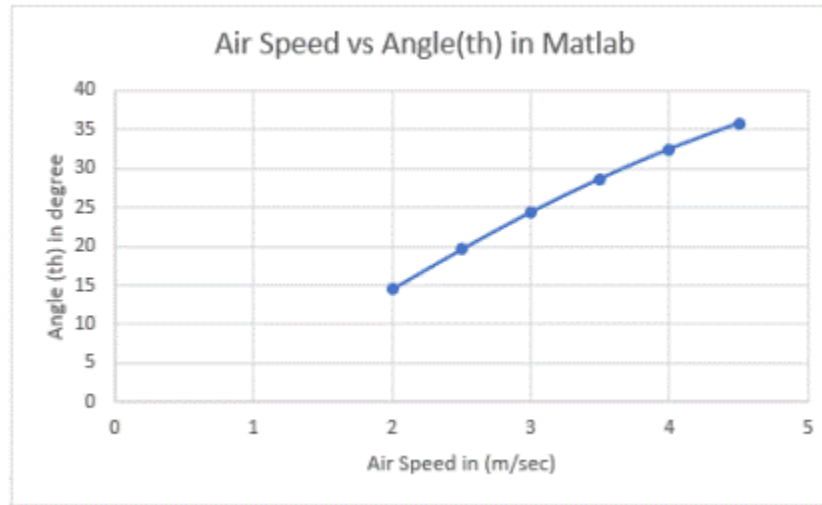
Figure 10 Air Speed vs Angle(th) in MATLAB

## The test of real tool: -

By getting benefit of the theoretical calculations above, it is possible now to build the real tool and test it in reality.   In real test, A PROSTER brand anemometer is used to measure the speed of air, as shown in Figure 11, knowing that the measurement of air speed is done at the position adjacent to the frame's cylinder.

Instead of using hot gases, a normal temperature air is used in the experiment because the professional instrument (PROSTER brand) does not work with high temperature as well as the duct and other auxiliary tools used in the experiment will get damage with high temperature. Besides there is no need to check for the thermal stresses because more than enough clearness is used to give space for thermal expansion.

Also, the flow of air is set to be through a duct, as shown in Figure 11 to obtain a homogenous flow profile and to avoid any external disturbance. The duct has a dimension of 2 m length, 0.35 m height and 0.3 m width. This size of duct is enough for maneuverings and to use other auxiliary tools like pliers and holding clamps.

Also, the magnitudes of angles are manually written on the auxiliary plate part to avoid using protractor during the experiment i.e., the auxiliary plate itself works as protractor during the experiment and as speed scale after the experiment.
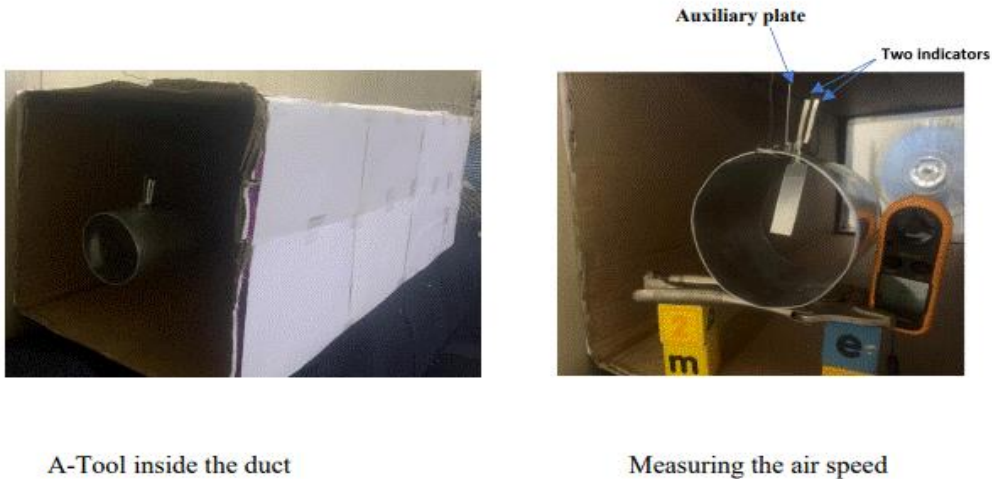
A-Tool inside the duct   Measuring the air speed

Figure. 11 Speed Measurement

Note: - Two indicators are glued to the paddle, as shown in Figure 11 above, instead of one indicator because it is planned in future to modify the tool to read speed in vertical direction as well as the horizontal one. Therefore, two indicators are glued, one is for horizontal gas flow and other is for vertical. The vertical gas measurements need some extra modification in design and new scaling for the speeds.

Also, there are several toy boxes to carry the Locking Plier which holds the professional instrument (PROSTER brand) to face the air in same direction as cylinder faces.

In the test, seven different air speed magnitudes are used to measure their corresponding angle values as shown in Table 2 as well as in Figure 12.

Table 2 Relation between Air speed and Real Angle (th)

| Air Speed	Real Angle Measuring
2	10
2.5	17
3	30
3.5	35
4	40
4.5	42
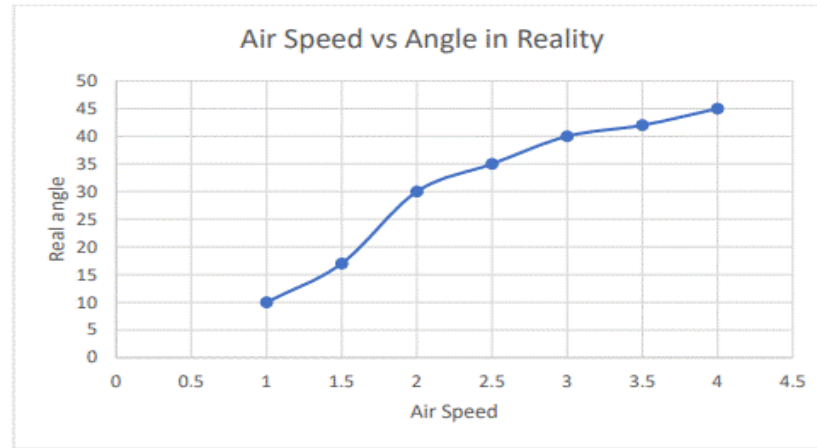
Figure 12 Air speed vs Real angle readings

Results and Discussions:

If the two results (theoretical and practical) are compared, it can be concluded that:

1. The weight of the paddle in reality is measured and it is a little higher than that computed with MATLAB because there are some extra edges left when building the part. Also, it is impossible to build an exact perfect-dimensions piece as in craft software.

2. The plots of seven air speeds with their corresponding angles, in both theoretical and experimental cases, are shown in the Figure 13 below. The seven angles in experimental case have less magnitudes than in theoretical case because the weight of paddle in practical case is higher than in theoretical case. Besides the two indictors might work as a secondary little paddle on opposite side of the main paddle and that will cause a negative moment around the pin with respect to the main moment resulting in air streams (thrust) on the paddle surface. Also, the air streams in reality are not ideal as in theoretical case i.e. Some streams' directions may not be totally horizontal.
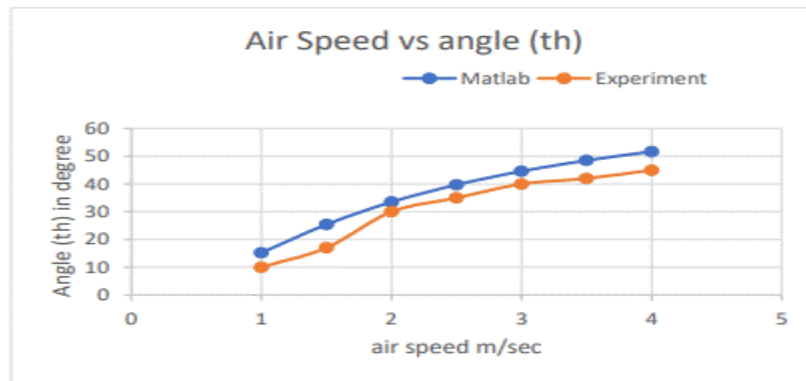
Figure 13 Air Speed vs Angle

3. Despite the simple design of this anemometer tool with some inevitable faults in its building, but the response of this tool to different air speed magnitudes coincides with the professional instrument (PROSTER brand) used to measure the speed. Besides when the professional instrument fluctuates around certain speed magnitude, the tool's indicator fluctuates too. That fluctuation is a result of a turbulent in air due to non-uniform air streams leaving the fan.

4. The tool is strongly recommended to mount in horizontal level and be in parallel with direction of the air or gas because the assumptions, rules and formula used in designing are only for horizontal case. In future, there will be a separate study on how to combine both horizontal and vertical cases on the same tool.

5. The handle in this experiment is two wires hanging the tool in its front and rear. Those wires are flexible and do not hold the tool well. It causes the tool to swing a little during air flow and that will affect the readings. It is possible to design a professional handle for this tool to help mounting the tool in better way.

6. It is impossible to use normal electronic sensors with this tool to read the measurements because those electronic devices do not tolerate high temperature. Although there are special sensors tolerating the high temperature, their prices are very expensive.

From the results and discussion above, this tool can be used to measure the speed of hot gases leaving furnaces, thermal engines, and jimmies but it should be placed at the end of the gas' passage to let gas cool a little and to avoid turbulence in flow as low as possible. Also, the tools can be used to measure the speed of a normal temperature air leaving fans and different aerodynamic application but the speed of air should be within the range of working the tool.

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تصميم وتصنيع انيموميتر للغازات الساخنة من مواد متوفرة ورخيصة

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الخلاصة:-

تم تصميم اداة قياس سرعة الغازات الحارة، التي لايمكن قياس سرعتها بالاجهزة التقليدية، من مواد رخيصة جدا متوفرة من بقايا عمليات التصنيع في الورش والمصانع الصغيرة. تم الاخذ بنظر الاعتبار اثناء التصميم ان من يقوم ببناء المفتاح هم التقنيين والحدادين المبتدئين. تم رسم أجزاء الاداة . في بداية العمل باستخدام برنامج الكاتيا، ثم تم عمل نموذج رياضي للموديل بأستخدام برناج انسس وووركبنج ٢٠٢٠ لفحص الاجهادات الميكانيكية المصاحبة لارتفاع الحرارة لاجزاء الجهاز وحساب مقدار التشوهات الناتجة من تلك الاجهادات بالاضافة الى حساب السماحيات الواجب تركها بين أجزاء الاداة لتجنب تلك الاجهادات. تم بعدها دراسة الموضوع نظريا لأحتساب الازاحات (الزاوية) التي تتحركها الاداة، اثناء تعرضها للهواء بأستخدام معادلات تم حلها بواسطة برنامج الماتلاب. تم اختيار سرعات هواء المختلفة لأيجاد ما يقابلها من إزاحة زاوية وتلك السرعات هي (١ , ١.٥ , ٢ ,٢.٥ , ٣ , ٣.٥) بوحدات متر\ ثانية. بعد ذلك تم بناء الاداة عمليا استنادا الى النتائج والحسابات النظرية، وتم وضعها في دكت بابعاد(٢ متر طول، ٠.٣٥ متر ارتفاع و ٠.٣ متر عرض) يمر به هواء بسرع مختلفة لمعرفة مقدار الازاحات الناتجة طبقا الى قيم السرع المختلفة. تم استخدام جهاز خاص لقياس سرعة الهواء في الدكت لتسجيل مايقابلها من ازاحة زاوية للاداة. وتمت أخيرا مقارنة النتائج النظرية والعملية وتبين هنالك فرق صغير نسبيا في قراءة الازاحات الزاوية بالإضافة الى أن تلك الاداة تستجيب بشكل جيد للتقلبات في سرعة الهواء مع جهاز قياس سرعة الهواء.

الكلمات الدالة:- الازاحة الزاوية، سرعة جريان الهواء، اجهادات ميكانيكية حرارية، انحرافات، عزوم، قوى رد فعل، احتكاك.