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JOURNAL OF UNIVERSITY OF BABYLON For ENGINEERING SCIENCES (JUBES)

Vol.29, No.2.| 2021

Design and Manufacturing of Pneumatic Switch from Available Cheap Materials

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Received:	3/8/2021	Accepted:	22/9/2021	Published:	21/10/2021

Abstract

This work is to build pneumatic switch, especially depending on air or gas flow, from a very cheap parts available as a waste material in reforming shops and small factories. Also, this pneumatic switch is carefully designed in a way that any primitive technician or smith can build it. At the beginning, the parts of switch are designed using Catia Software and some parts are imported to ANSYS WORKBENCH 2020 R2 software to check the mechanical stresses associated with loads. Then, theoretical computations are made where the angular displacement is calculated, based on equations solved by MATLAB software, when the switch faces flow air stream for different speed magnitudes. After that, a real switch is built and be subjected to those same different air speed magnitudes used in theoretical computations. Then, comparison between the two results is made, which show there is a relatively slide difference in angular displacement readings as well as the switch has enough strength to resist the loads based on what is computed in theoretical side and what is noted in practice.

Keywords: Angular displacement, Air flow speed, Deformation, Stresses, Moments, Centroid.

Introduction: -

This paper is the first step to build a fully automatic controlled air conditioning (HVAC) and heating system. Because of non-genuine parts available at Iraqi markets and the parts' high price, there is a need to build parts by ourselves as long as there is a possibility for that. Pneumatic switch works as feedback for air, where room temperature changes, and it is used in other industrial applications like well pumps, furnaces, etc. where the gases are used and their temperatures changes [1]. A pneumatic switch like pressure switch is working on principle of closing the electric circuit when a pressure, coming from pneumatic or hydraulic sources, is reached to a certain amount based on the previous settings value. Those pneumatic switch can either work on pressure rise or pressure fall [2]. " Pressure switches are available in four types: diaphragm, bellows, bourdon-tube, and piston." [3]. Many factors should be considered to choose the right type of switch like life of a pressure switch, types of sensing elements, wetted parts, pressure range, switch point, set point adjustment, types of housing. [4]. Generally, the pressure range, used in air-conditioning and heating system, is a low-pressure range because this switch is used as an air flow sensor and to detect any restrictions or leak in the air path [5]. Other type of pneumatic switch is the flow switch which is working on closing and open the electric circuit based on the flow of air or gas. This flow switch is described as mechanical device that can be set depending on the movement of gas or air [6]. There are several types of flow switches depending on the way of detecting the flow of the gas therefore they are characterized as doppler, paddle, thermal, magnetic, and ultrasonic [7]. The paddle and the magnetic type are primary device and are placed in channel where the liquid or gas flows. A transducer or on/off mechanical switch is mounted to the paddle switch and be connected to an electrical circuit. This transducer

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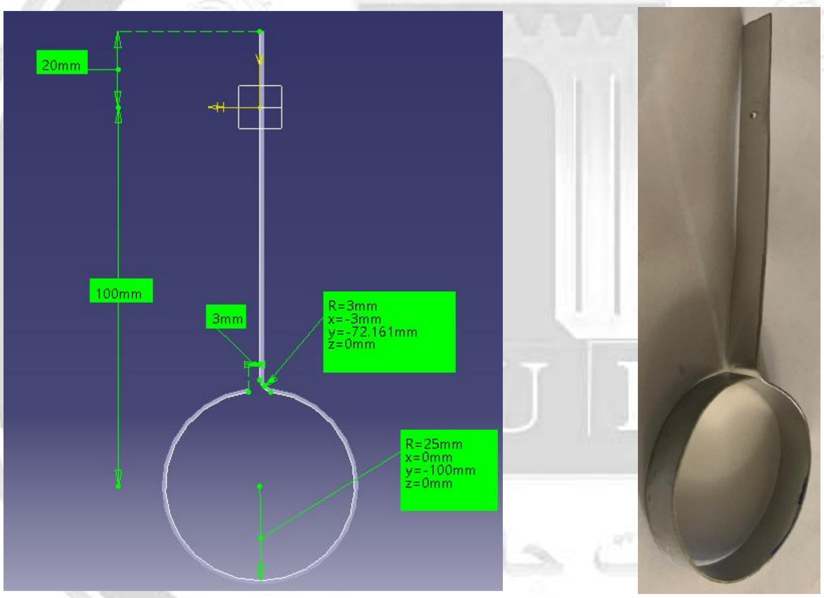
or the on/off mechanical switch closes or opens the circuit depending on the displacement of the paddle. [8]. Therefore, the aim of this paper is to design and build a special paddle switch to detect the flow of air depending on previously setting flow amount.

Materials and Methods:

The only material used to build the switch is Aluminum to avoid the rust generated from humidity in air. The steps of designing this switch should consider the strength of its parts, range of working, and the environment of working. The switch generally consists of three main parts, the arm, the drum, and the holder. The dimensions of these parts are selected to be suitable for using the switch inside or outside the ducts with enough accurate results. The parts of switch are:

1. The arm is a rectangular aluminum plate having a thickness of 0.9 mm. One side of this plate is bent to 50mm diameter circular shape. Also, a hole of 1mm diameter, is drilled at 20 mm distance from other side of the arm (where the coordinate arrows are). The dimension of the arm is as shown in figure.1 below.



Arm in Catia software **real arm picture**

Fig (1) Front view of the arm part (Aluminum)

Note: The arm is drawn by CATIA software and is built in reality as shown in figure 1 above

2. The second part is the drum. The drum is made from 0.04 mm thickness aluminum sheet or aluminum foil (used for cooking purposes) due to its being cheap besides it is available in everywhere. This piece of sheet is formed as semi- spherical shape and is placed inside that circular shape of the arm to face the air or gas steams. In real prototype, the drum was deliberately formed in a little rugged form where it has a non-uniform terrain to highly consider how primitive smith or technician can form it. The edge of drum is bent as shown in figure. 2 below in order to engage to that circular part of the arm for holding. Also, this part is drawn in CATIA software and is built in reality.

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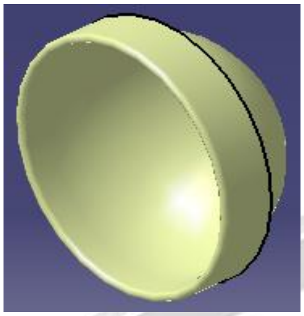

Drum in Catia

Real drum picture

Fig. 2 the drum

3. The third part is the holder, which is like a chassis or frame of automobile. The holder is made from 1 mm Aluminum plate thickness as shown in figure 3 below. The arm part is binned to the holder and a sensing element is mounted on the holder as well. the holder is mounted on the duct in which the flow air streams are and thereby the whole switch is mounted.

Fig. 3 Real Pictures of holder

The whole real switch after assembling is shown in figure. 4 below

Fig. 4 whole real switch

Principle of work:

When the streams of air or gas faces the drum, it will push the drum away at a distance proportional to the flow rate of air or gas and thereby the arm will move in angular displacement, proportional to the flow rate too, around the pin. The other top free end of the arm, not the circular one, will move and be adjacent to the sensing part which will detect the motion depending on previously setting position of the sensing element from the arm.

To build this switch, a theoretical and practical procedures are required. Therefore, there are two sections: -

First: Theoretical section: -

Strength check:

The parts of this switch will subject to stresses within the operation and those stresses need to be check to avoid failure within operation. The drum will have the less stresses among other part because of its shape in which the loads will be distributed on larger area [9]. The arm has most stresses and a mathematical model is made to compute those stresses using ANSYS WORKBENCH 2020 software. In arm part, the element mesh used is a tetrahedrane element type with about 4690 elements [10]. As shown in figure 5 below, A fixed boundary conditions is at the face of the other arm's side or position B in figure. The cylindrical support is defined at the hole or position A, which represent the joint. As well as a load results in air stream on the drum is applied to the ring (circular shape) of the arm directly. The amount of that load is 100 Pa which is computed by dividing the fluid thrust to the area of the ring of that circular part facing the fluid's streams. The fluid thrust is computed when the speed of air is about 10 m/sec and the angle (th) is zero to get maximum thrust as will be explained later in the angular displacement calculation section. This speed rate of (10 m/sec) is too high as a compare to different speeds applied to the switch in reality.

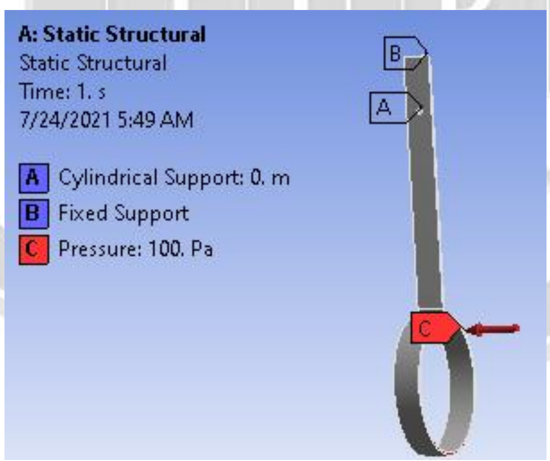

Fig. 5

The solution is done and results are obtained as shown in figure 6 below. From the results shown in figure 6a, it can be seen that the maximum von messes stress is at the ring or circular part of the arm but it is within the design limit because its amount is about 223.86 KPa which is far from the yield stress (276 Mpa) [11]. Also, the maximum deformation amount is 1.5e-5 m at the circular part of the arm as shown in figure 6b

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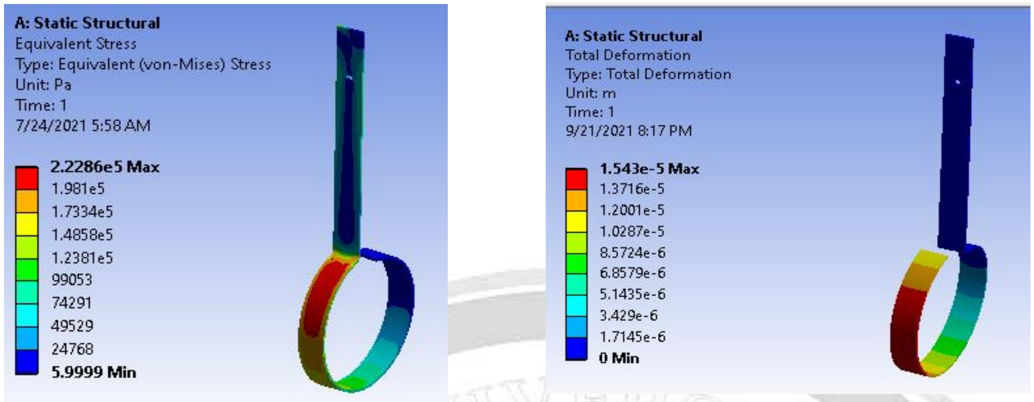

a. maximum von messes stress of arm **b. Total deformation of the arm**

Fig. 6 Workbench Results

<u>Angular displacement computation of arm:</u>

The theoretical part is to compute the angle where the moment resulting from the air's thrust is equal to the moment resulting from the weight of the assembly (arm and drum) about the pin. There is a need to find the weight and the centroid of the assembly (arm and drum). A mathematical calculation is required to compute this angle therefore, a MATLAB code is written to do all the calculations. But before going on with MATLAB, there is a need to define several parameters, as shown in figure 7 below, which are used in the code. knowing that all length units used in the code are in meter.

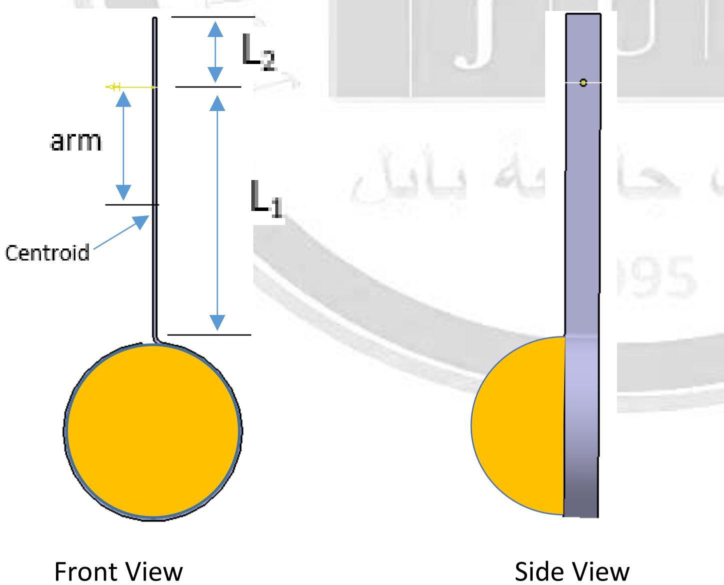

Fig. 7 Parameter on Arm and drum

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```
d=2e-2;          % dimeter of the drum
L1=10e-2;        % Length of the arm
L2=2e-2;         % Length of lever connecting to the switch
rou=1;           % density of air
v=2;             % speed of air
dens= 2710;      % density of aluminum
t= 0.001;        % thickness of arm
tsh=0.036e-3;    % thickness of drum's sheet
wd=1e-2;         % depth of the arm
```

Using Fluid Dynamic formula: according to the figure 8:

The force applied to the arm by the air stream is [12]:

$$f= rou*A*v\{v-[v*\sin(th)]\} \quad \text{——— 1}$$

Where: -

f- thrust force by the fluid on the arm
A- area of the circular part of arm
v - Speed of air
rou- density of air
th- angle between the arm and the vertical

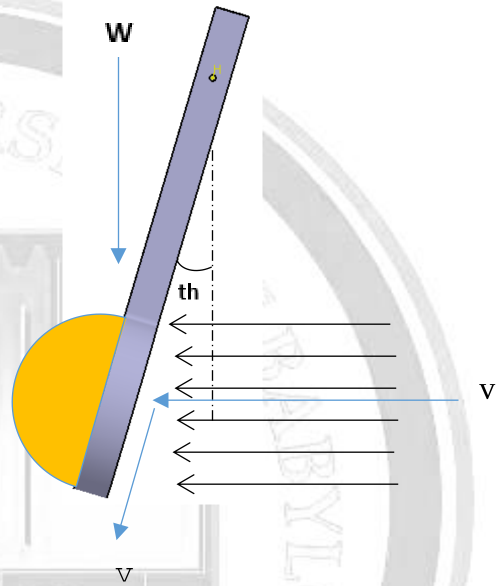

Figure 8

$\sum$ Moment about the pin = zero

$$f*(L_1+\frac{d}{2})*\cos(th) - w * arm * \sin(th)=0 \quad \text{——— 2}$$

Where: -

w - the weight of the assembly (arm and drum)

d- diameter of the drum

Substituting the thrust equation into moment equation:

$$rou*A*v\{v-[v*\sin(th)]\}*(L_1+\frac{d}{2})*\cos(th) - w * arm * \sin(th)=0$$

The equation above is unusual equation to be solved for (th) term in conventical mathematical way, therefore trial and error method is used to solve this equation [13]. MATLAB code is a useful tool for such solution [14] as shown in figure 9

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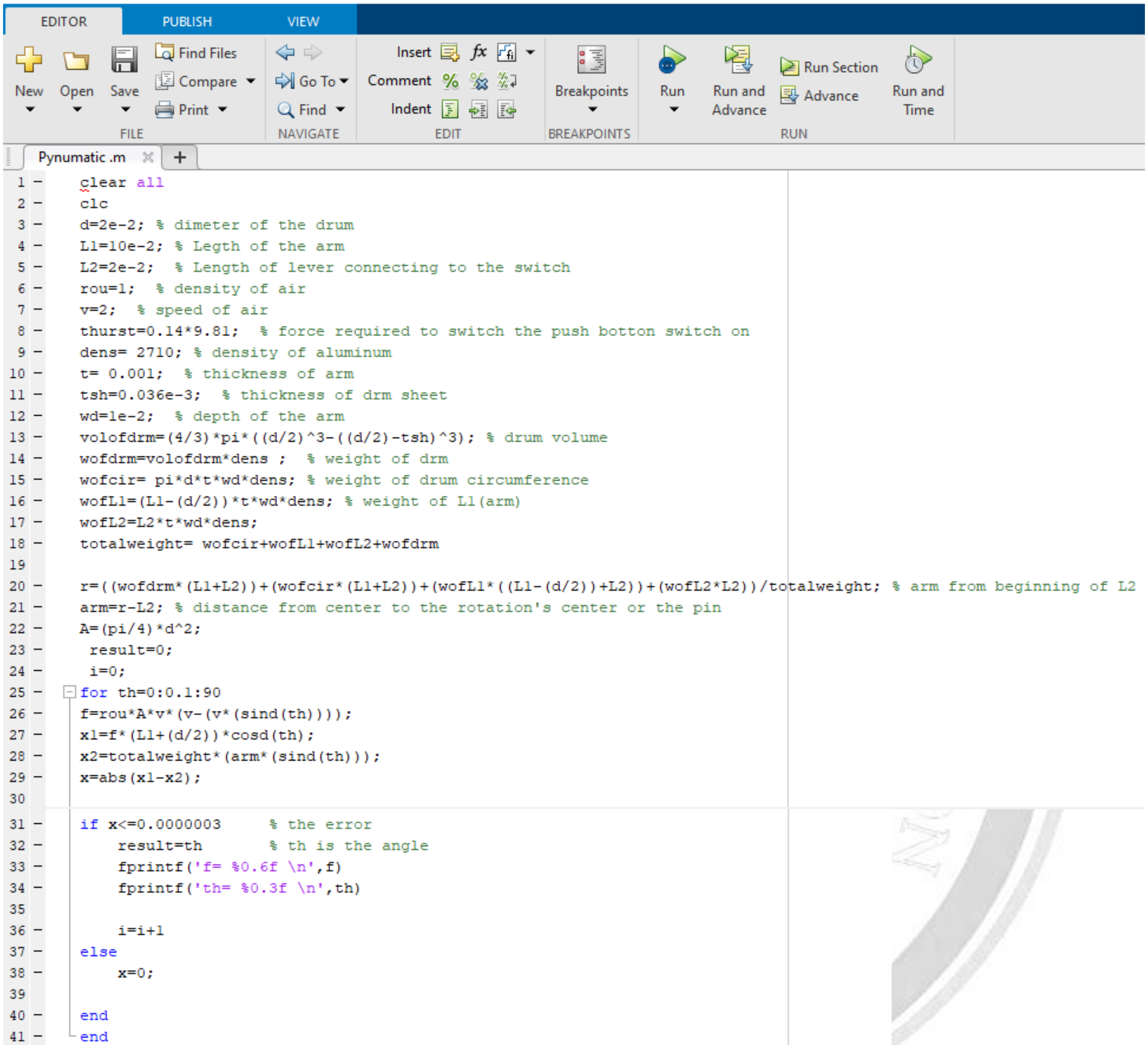

```
clear all
clc
d=2e-2; % dimeter of the drum
L1=10e-2; % Legth of the arm
L2=2e-2;  % Length of lever connecting to the switch
rou=1;  % density of air
v=2;  % speed of air
thurst=0.14*9.81;  % force required to switch the push botton switch on
dens= 2710; % density of aluminum
t= 0.001;  % thickness of arm
tsh=0.036e-3;  % thickness of drm sheet
wd=1e-2;  % depth of the arm
volofdrm=(4/3)*pi*((d/2)^3-((d/2)-tsh)^3); % drum volume
wofdrm=volofdrm*dens ;  % weight of drm
wofcir= pi*d*t*wd*dens; % weight of drum circumference
wofL1=(L1-(d/2))*t*wd*dens; % weight of L1(arm)
wofL2=L2*t*wd*dens;
totalweight= wofcir+wofL1+wofL2+wofdrm

r=((wofdrm*(L1+L2))+(wofcir*(L1+L2))+(wofL1*((L1-(d/2))+L2))+(wofL2*L2))/totalweight; % arm from beginning of L2
arm=r-L2; % distance from center to the rotation's center or the pin
A=(pi/4)*d^2;
 result=0;
 i=0;
for th=0:0.1:90
f=rou*A*v*(v-(v*(sind(th))));
x1=f*(L1+(d/2))*cosd(th);
x2=totalweight*(arm*(sind(th)));
x=abs(x1-x2);

if x<=0.0000003      % the error
    result=th        % th is the angle
    fprintf('f= %0.6f \n',f)
    fprintf('th= %0.3f \n',th)

    i=i+1
else
    x=0;

end
end
```

Fig. 9 MATLAB Code to compute an angle (th)

From MATLAB code, the distance from the centroid to the pin hole is computed to be 0.0836 m. Also, the weight of the assembly (arm & drum) is 0.0048 kg.

In the code, five different magnitudes of speed are used to find out their corresponding angle values and it can be noted that the angle is proportional to the air speed as shown in table .1 and figure 10

Air Speed	Angle in MATLAB	Error
2	14.5	0.00000035
2.5	19.6	0.00000037
3	24.4	0.00000017
3.5	28.7	0.00000005
4	32.5	0.00000023
4.5	35.8	0.00000042

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

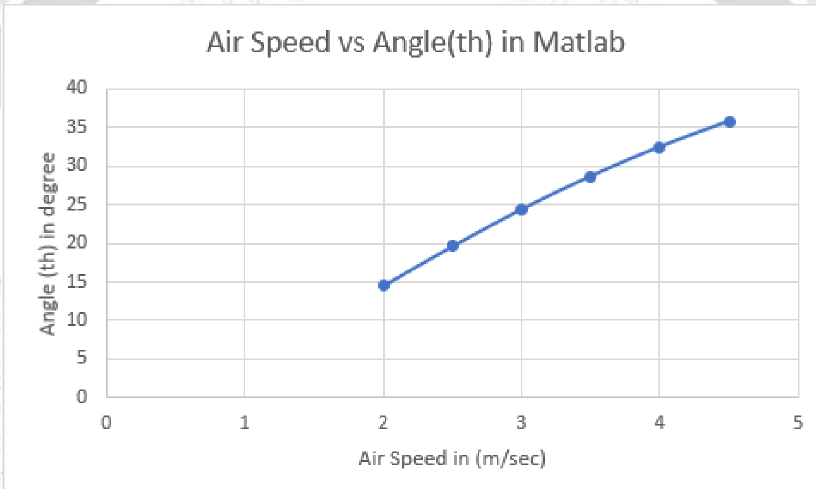

Fig. 10 Air Speed vs Angle(th) in MATLAB

Second: - <u>The experimental section:</u>

For the strength of material, all switch parts hold all the loads in the experiment in very well form. The deformation result in loads cannot be measured because it is too small for Micrometer used as measuring tool in this experiment.

A real switch is built and the weight of the assembly (arm &drum) is measured. 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 of the drum. It is very difficult or impossible to use a duct and place the switch inside because the duct does not have enough space for maneuvering and for other auxiliary tools necessary for the experiment like, pliers, holding clamps, protractor and others. Therefore, a normal home fan without duct is used to generate an air flow.

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Measuring the angle **measuring the air speed**

Fig. 11

In the experimental work, some simple physical methods are used to weight the assembly (arm& drum) and locate its centroid. A normal small balance is used to weight the assembly. The centroid is located by holding the assembly using point clamp and moving the clamp along the arm till equilibrium is reached. The distance from the centroid to the pin hole is about 0.1 m and the weight of the assembly is 0.0056 Kg. Five 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	Angle in MATLAB	Error
2	14.5	0.00000035
2.5	19.6	0.00000037
3	24.4	0.00000017
3.5	28.7	0.00000005
4	32.5	0.00000023
4.5	35.8	0.00000042

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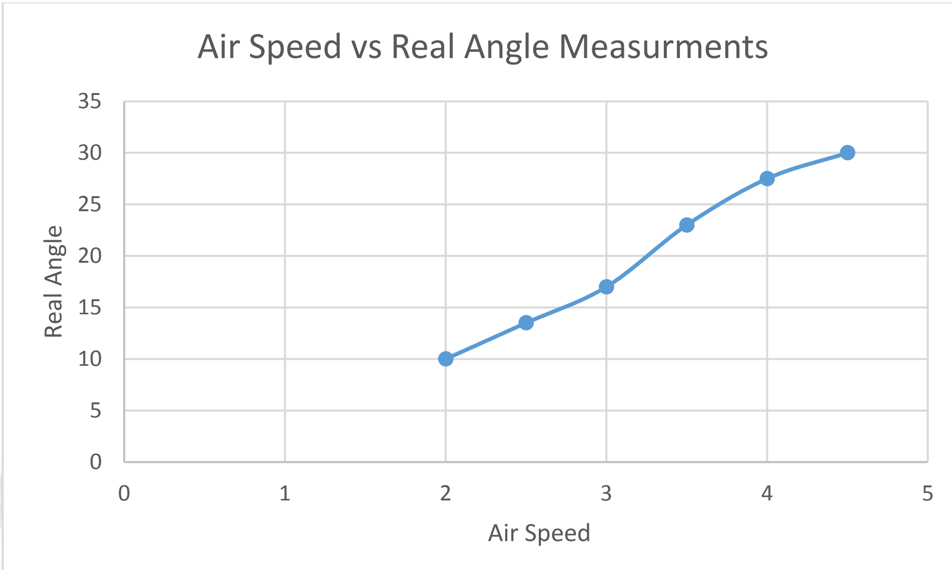

Fig. 12 Air speed vs Real angle readings

Results and Discussions:

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

1. The weight of the assembly in the practical case is higher than in theoretical case because the drum in theoretical case is supposed to have a uniform surface without any ragged or deformation. while in practical case, the drum is formed from foil sheet, therefore a ragged and non-uniform surface will certainly be form which indicate an increment in weight.
2. Because of the increment of the drum's weight, the centroid of the assembly in practical case is more near to the drum than in theoretical case.
3. The angles of the theoretical and experimental cases with air speed are plotted together as shown in the figure 13 below. Generally, the angles in practical case have less magnitudes than in theoretical case because the weight if the drum in practical case is higher than in theoretical case as well the centroid of assembly in practical case is more far from the pin than in theoretical case. Therefore, the weight will have longer arm to generate moment in order to resist the moment formed by the air thrust.

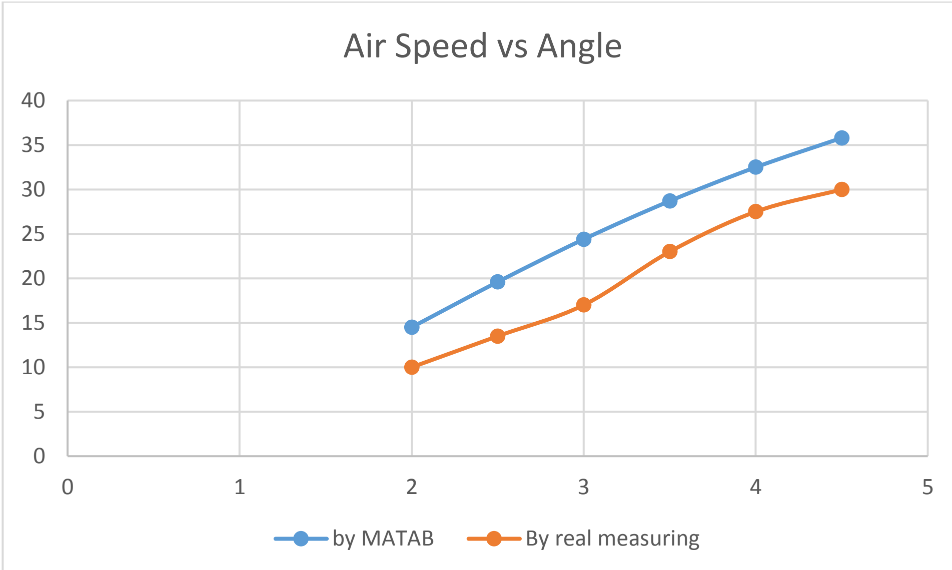

Fig. 13 Air Speed vs Angle

4. During measuring of the angles in practice, the readings of angles are fluctuating around certain magnitude i.e. the readings are unstable. That is because there is a turbulent in air flow as a result of non-uniform drum surface as well as the readings are taken at a region very near to the fan (source of air streams or air speed).
5. The practical angles do not follow the same path as the theoretical angle because of unprecise readings associated with the turbulence. Also, in theoretical case. It is assumed that air streams are in perpendicular circumstance with drum. While in practical case, the whole switch is held by hand so it is impossible to obtain fully perpendicular case with air stream.
6. This switch should be placed inside the duct near the outlet and be far from fan to avoid the turbulence. Also, it is strongly recommended to mount the switch in such a case that its holder is in horizontal level and be in parallel with direction of the air or gas.
7. Because this switch is made from metal (aluminum), it can be used in industrial purposes, if the sensing element are suitable for industrial application, where high temperature is and different toxic gases are.

In future work, a sensing element will be chosen to be suitable for the application. Also, if it is possibility, this switch might be modified to be used as industrial anemometer because of its being suitable for industrial applications.

Acknowledgments:

Sample of Acknowledgments Sample of Acknowledgments Sample of Acknowledgments.

Conflict of interests.

There are non-conflicts of interest.

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Vol.29, No.2.| 2021

تصنيع مفتاح كهربائي غازي يدويا طبقا الى خطوات علمية

احمد حمد يحيى البربن

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الخلاصة

تم تصميم مفتاح الكهربائي المعتمد على المائع(الغاز) او على جريان المائع من مواد رخيصه جدا متوفره من بقايا عمليات التصنيع في الورش والمصانع الصغيره. اثناء التصميم، تم الاخذ ينظر الاعتبار ان من يقوم ببناء المفتاح هم التقنيين والحدادين المبتدئين. في البدايه تم رسم أجزاء المفتاح باستخدام برنامج الكاتيا ثم تم عمل نموذج رياضي للموديل بأستخدام برناج انسس ووركبنج ٢٠٢٠ لفحص الاجهادات الميكانيكيه للمفتاح ومقدار مقاومته للاحمال المصحوبه اثناء العمل. بعدها، تم دراسة الموضوع نظريا حيث تم احتساب الازاحات (الزاويه) التي يتحركها المفتاح اثناء تعرضه للمائع بأستخدام معادلات تم حلها بواسطة برنامج الماتلاب. بعد ذلك تم بناء المفتاح عمليا ثم تم تعريض ذلك المفتاح الى سرع مختلفه لمعرفة مقدار الازاحات الناتجه. وأخيرا، تمت مقارنه النتائج النظريه والعمليه وتبين هنالك فرق صغير نسبيا في قراءه الازاحات بالإضافة ان المقاومة الميكانيكية للمفتاح عالية للأحمال المصمم لها.

الكلمات الدالة: – الازاحة الزاوية، سرعة جريان الهواء، اجهادات ميكانيكيه، انحرافات، عزوم، مركز ثقل.

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