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A Labview Based Optimization of Supersonic Wind Tunnel Instrumentation Systems

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ABSTRACT

Indonesian National Institute of Aeronautics and Space (LAPAN) has got a supersonic wind tunnel aimed at conducting research in high-speed motion object. In the past, the condition made the access on LAPAN's supersonic wind tunnel limited; which also made this device could only be used for the shockwave observation utilizing the schlieren apparatus. As a consequence, the data acquisition system could not collect data from sting balance; as some of the control panels were either a non-operational or in need of calibration. Based on these conditions, this research was conducted in order to develop a new integrated control system and data acquisition. Furthermore, the system was built based on the PXIe module from National Instrument and LabVIEW graphical programming which was used as the user interface, so that it could achieve the effectiveness of operation in terms of the time and the better data quality. In the recently developed system, the angle of attack (AoA) control—which was operated manually in the past—had been optimized into a digital control using a PID control method. As the AoA control had successfully become automated, there is a new testing option for moving the AoA; while the wind tunnel is running. In terms of data acquisition, the result after the optimization shows that it can collect better data (the noise /interference becomes smaller than the previous data), and now the data from the balance, the pressure data, the AoA position, and block position can be recorded.

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1. INTRODUCTION

A wind tunnel is an experimental facility which is used to study the aerodynamic characteristics of test models having similarities based on geometry, kinematics, and dynamics with full-size objects [1].

At the Indonesian National Institute of Aeronautics and Space, there is an aerodynamic laboratory which has 4 testing facilities: the subsonic wind tunnel, the transonic wind tunnel, the supersonic wind tunnel, and the Computational Fluid Dynamics (CFD) tunnels for simulation testing. The supersonic wind tunnel is one of the aerodynamic test facilities used for research and testing of vehicles or objects operating at high speed. Figure 1 shows the schematic of the supersonic wind tunnel based on its function.

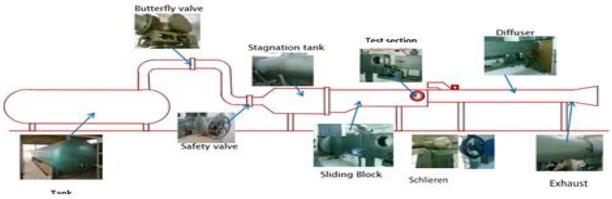

Figure 1. LAPAN's Supersonic wind tunnel schematic

Caption:
- Tank : Air storage for wind tunnel testing.
- Butterfly valve : For open or close the airflow from the tank.
- Safety valve : For manually open or close the airflow.
- Stagnation tank : Reducing the flow turbulence before entering the test section.
- Sliding Block : To control the speed of the airflow.
- Schlieren apparatus : To visualize the shockwave of the test object.
- Test section : To place the test object.
- Diffuser and Exhaust : The airflow outlet after passing through the test section.

Basically, the wind tunnel works by simulating the fluid flow in the test specimen [2], in this case, a supersonic wind tunnel is made to produce airflow at supersonic speed and used for testing and analyzing the test object or scale models under controlled environmental conditions [3, 4]. The flow speed for a supersonic wind tunnel categorization are 1.2 < M < 5 [5]. M here represents Mach number, which is not a unit. Mach number is the comparison of the relative speed of an object to the speed of sound [6]. The LAPAN's supersonic wind tunnel built by Aerolab in May 1983 had experienced a decrease in performance and functions in some parts, which made the supersonic wind tunnels unable to operate optimally. There are several parameters which need to be optimized in order to make the wind tunnel work normally; they are angle of attack (AoA) control system, sliding block control system, and data acquisition system for sensor reading. This research was conducted to create an integrated control system design and data acquisition that was aimed at optimizing the work function and better data quality of the supersonic wind tunnel.

2. PROPOSED METHOD

The supersonic wind tunnel instrumentation system consists of two parts; the data acquisition system (data acquisition of sting balance and data acquisition of pressure transducer) and the control system (angle of attack and sliding block control). Both systems are 2 different systems which are set in 2 different panels operating by two operators. In this study, both systems are replaced with a new system using a data acquisition and control system from National Instrument in order to make it be able to be operated as one system of supersonic wind tunnel instrumentation system. The design of the supersonic wind tunnel instrumentation system is shown in Figure 1.

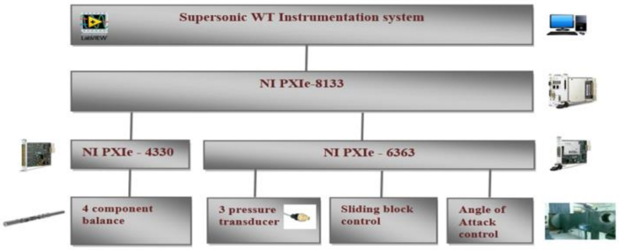

Figure 1. Instrumentation design for LAPAN's supersonic wind tunnel

2.1. Sting Balance Data Acquisition System

In the wind tunnel testing, the forces and moments experienced by the test object can be observed by using the balance as an instrument serving as a sensor in order to obtain the data [7]. There are 2 types of balances commonly used in the wind tunnel; the external balance and the internal balance [8]. In the supersonic wind tunnel, LAPAN uses an internal balance which can also be called a sting balance.

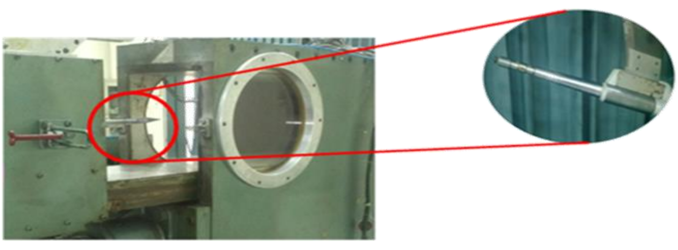

Figure 2. Sting balance for LAPAN supersonic wind tunnel

Figure 2 shows the LAPAN's sting balance which is attached to the test section. The sting balance owned by LAPAN's supersonic wind tunnel is a 4 components sting balance. It's function is to read the forces or moments experienced by the test's object. The forces and moment are Normal 1 (N1), Normal 2 (N2), Axial (Ax), and Roll (R). The existing data acquisition system will be replaced with the new data acquisition from National Instrument so it can reduce the noise or the interference of the resulting force. PXIe 4330 series' module is used to measure the forces and moments from the sting balance. The data acquisition system for sting balance which is using the PXIe 4330 is shown in Figure 4.

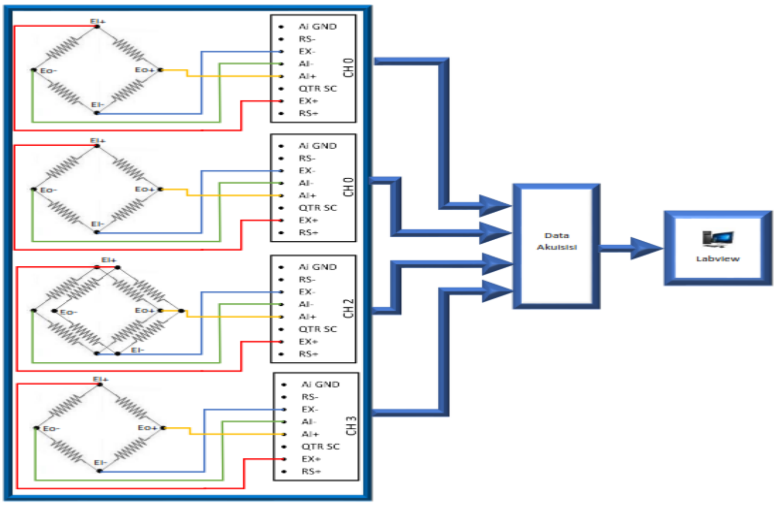

Figure 3. Sting balance DAQ schematic for supersonic wind tunnel

PXIe 4330 is a data acquisition module from National Instrument serving as data acquisition and signal conditioning for the bridge sensor. **Error! Reference source not found.** shows how the sting balance data acquisition system works. PXIe data acquisition gives excitation to the strain gauge attached to the sting balance. At the time when the sting balance experiencing deformation due to the load given, the PXIe read the change of resistance from strain gauge which then converts the output into force and moment units.

After integrating the data acquisition system, the next step to do is sting balance calibration. The calibration process uses the measured loads assigned at a particular point on the sting balance according to the value to be measured (N1, N2, Ax, and R). The first step in the calibration process is placing the calibration rig on the sting balance that is followed by placing a series of loads on the calibration rig with fix increment. The data is recorded by the PXIe 4330. The calibration process is repeated for 3 times.

2.2. Pressure Sensor Data Acquisition System.

In the pressure sensor data acquisition system there are 3 sensors that are going to be utilized; they are the tank pressure sensor, the stagnation pressure sensor, and the static pressure sensor. Each of them has different maximum pressure capacities; the tank pressure sensor of max 120 psi, the stagnation pressure sensor of max 100 psi, and the static pressure sensor of -14.7 to 15 psi.

The pressure sensors which are used here are the OMEGA industrial-scale sensor series (5b) aiming at the data quality results from the sensor to get better results which have a relatively good resistance. Meanwhile, the data acquisition system is using the PXIe 6363 from National Instrument (5a) which is a multi-purpose data acquisition module which has analog input, analog output, digital input /output, and counter.

Figure 4. a. PXIe 6363 b. Omega pressure transducer

The pressure sensor data acquisition process is started with the power supply to the sensor from PXI. At the moment when the measurement starts, the PXIe 6363 reads the voltage change from the sensor then converts it into pressure units. As for the pressure sensor calibration, the use of calibrator is utilized to find out the conversion value from the output voltage unit (V) to the pressure unit (Psi). The calibrator which is used to calibrate the pressure sensor is the DPG 4000 series, which also comes from OMEGA.

In the calibration process, the pressure calibrator provides a measured pressure to the pressure transducer so that the pressure transducer is able to produce the signal to be recorded by the data acquisition. The result of recording from the pressure transducer output signal is then compared to the pressure value from the pressure calibrator.

Using the Bernoulli equation [9], Mach numbers can be obtained from the ratio between the total pressure (p_o) and the static pressure (p):

$$\frac{p_0}{p} = \left(1 + \frac{\gamma-1}{2} M^2\right)^{\frac{\gamma}{\gamma-1}} \quad (1)$$

$$M^2 = \frac{2}{\gamma-1}\left[\left(\frac{p_0}{p}\right)^{\frac{\gamma-1}{\gamma}} - 1\right] \quad (2)$$

Where p_o =Total Pressure
p = Static pressure
γ = specific heat ratio for air = 1.4
M = Mach number

2.3. The angle of Attack Control System

The AoA control is required to adjust the angle of the object to get it tested against the flow direction. This is carried out to determine the forces and moments occurred in the test's specimen with various angle of attack (AoA). In the past, as shown in Figure 5, the angle of attack control were still performed in manual way in which the operator would manually drive the motor (with the control switch) while viewing the display of the angle of attack position until it reached the desired set point. The determination of sting balance motion speed was also still conducted manually (Figure 5). To prevent the missing out of set point values; the operator must also manually reduced the motor voltage supply to slow the motor rotation down to prevent overshooting. The angle measurement display became no longer exact (if it is compared to the inclinometer attached to the model). Although it only has a 1 to 2 degree angle difference, at the supersonic speed it is going to produce a considerable force or moment difference. In this research, the calibration is performed as well as the integration of the control system into a system integrated with the data acquisition system.

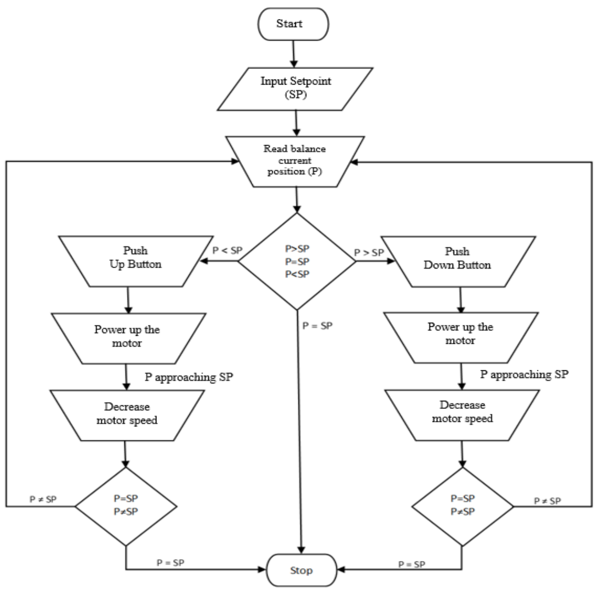

Figure 5. Angle of Attack manual control flowchart

The control design used for the angle of attack control system is developed by using a LabVIEW based PID system [10]. The AoA motor system uses an extra gearbox which creates a stepping movement in the sting balance AoA setting. As a consequence of that factor as well as the limit of time for conducting the research, the process of gain finding for the PID system was done by using the method of trial and error.

The development of the control system uses the hardware of PXIe 6363, the motor driver module, and the position sensor as feedback loop, and then finally all the components of hardware is assembled into 1 unit Angle of attack control system as shown in Figure 6.

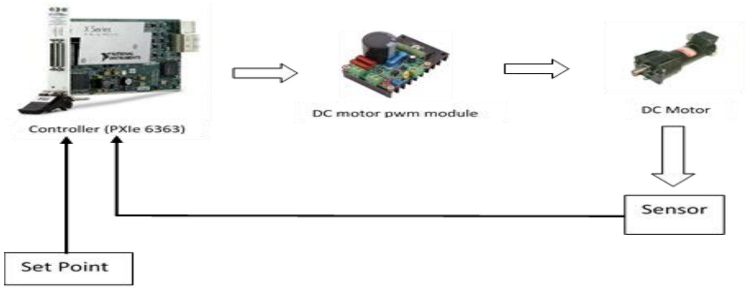

Figure 6. AoA control system schematic

Figure 6 shows the PXIe 6363 which serves as a controller, which functions to receive the set point data input, and also to receive the controlling duty cycle signal from the DC motor using the PWM module. The PXIe 6363 also accepts input data from the position sensor.

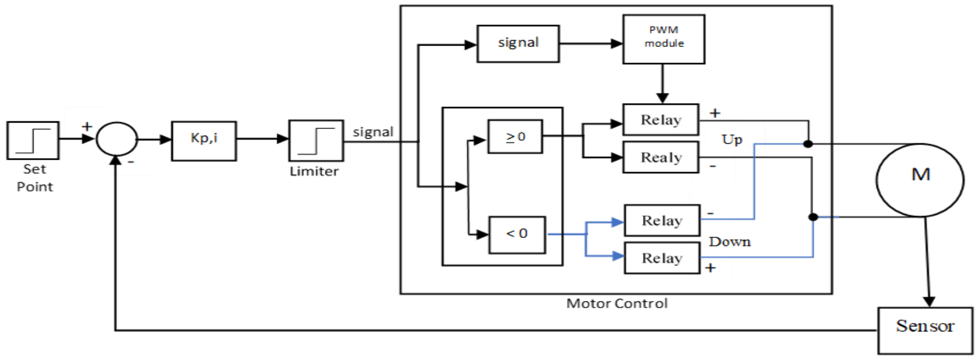

Figure 7. Angle of attack control system design

Duty cycle variation will affect the speed of the motor to move the sting balance. The design of the PID system that is used to control the angle of attack is shown in
Figure 7.

2.4. Sliding Block Control System

The sliding block control is much simpler; the motor speed setting is not required because the speed of motor rotation itself runs in relatively slow pace at only 20 rpm. The requirement for the system is torque; therefore a big torque motor is needed. Based on the flowchart in **Error! Reference source not found.**, it is obvious that after the known set point is acquired, the next thing an operator must taken care of is in knowing the position of the current block position. The position can be seen on the monitor screen, and after knowing the current position, the operator can decide whether the block position will move up or down. Adjusting the position has also been done with the new instrumentation

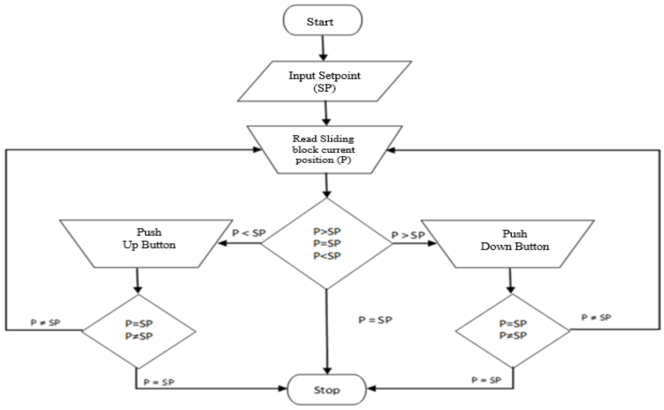

Figure 8. Sliding block control flowchart

2.5. LabVIEW

The LabVIEW programming language is used for the data acquisition system, control and also the user interface. The selection of LabVIEW as a programming language is because of its user-friendly and its graphical-based programming language which makes it possible to display the user interface that is easy to operate [10, 11]. It also offers a huge graphical programming capability which is able to make data logging become more flexible and powerful [12]. By using LabVIEW, we can start today to maximize performance on multithreaded operating systems and multiprocessor computers without increasing either your development time or the complexity of your application [13].

LabVIEW itself consists of a front panel and block diagram (Figure 9). The front panel is used as an interface which will be directly related to the user or the operator. While the block diagram is a program code that is made by the programmer based on the purpose of the system programming (control, data acquisition, and others).

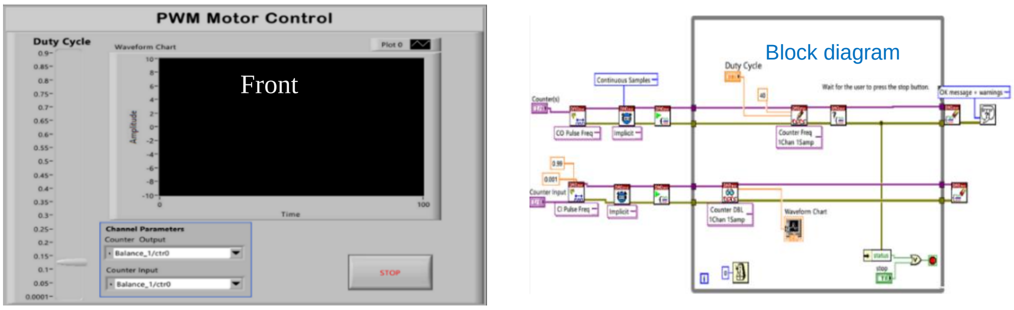

Figure 9. Front panel and block diagram in LabVIEW

3. RESULT AND DISCUSSION

After designing the integrated system for data acquisition and control system, the next step is implementing the design. With the new system, we can collect the data from the pressure sensor, sting balance, angle of attack position, and also controlling the sliding block position and the automated angle of attack position all in one system.

Calibration is needed to make sure the reading from pressure sensor, sting balance, and angle of attack is valid.The pressure sensor calibration data is used to convert the read data from voltage (V) to pressure (Psi). As for the angle of attack calibration, it is needed to verify the position of reading, and to convert it from voltage (V) to degree unit (º). The sting balance calibration is used to find out the character of the sting balance in the form of accuracy and linearity which became the important information before committing a measurement. The PXIe based integrated system for data acquisition and control system

hardware is shown in Figure 10.

Figure 10. PXIe based data acquisition and control system for supersonic wind tunnel

3.1. Data Acquisition System

- Pressure sensor calibration.

For pressure sensor calibration, the data acquisition collects the pressure sensor output in (voltage) as pressure is given with the pressure gauge calibrator. As seen in Figure 12, the calibration data have a linear trend. From that result, the equation for converting voltage (V) to pressure (Psi) is revealed.

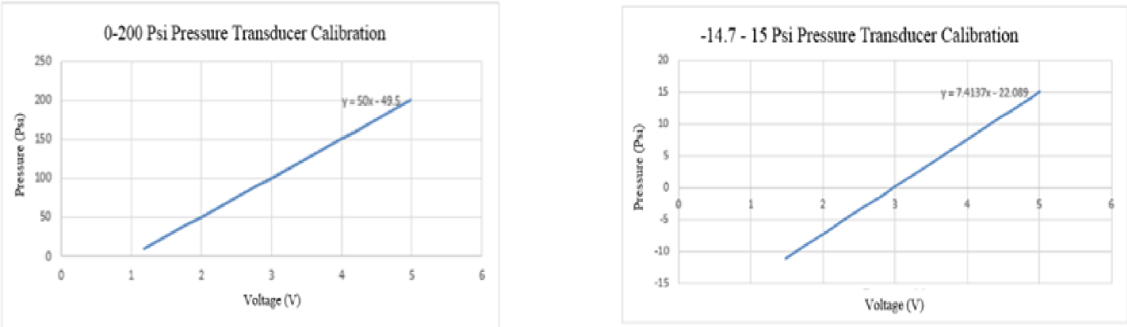

Figure 11. The pressure sensor calibration

- Sting Balance

The data acquisition for sting balance is used for collecting data from the calibration process and on wind tunnel test. From the sting balance, we can collect N1 Normal 1 (N1), Normal 2 (N2), Roll (R), and Axial (Ax) data. The calibration performed on the sting balance is required to find out the character of the sting balance in the form of accuracy and linearity which is important information before committing a measurement. The balance basically has a low coupling characteristic between each component source [1]. So when there is measurement of one parameter like the N1, the other parameters like N2, R and Ax can still be seen in a small value. But in this case, there are several problems affecting the measurement results such as high coupling effect and it also had a bad repetition value in repeated measurement.

With this new hardware and data processing program developed with LabVIEW, the coupling effect can be minimized and it is going get a better repetition value in a repeated measurement. Figure 14 to figure 16 are showing improvement in the calibration value after using the newly developed hardware and data processing program.

Figure 12. Sting balance calibration process

The calibration was performed by applying loads one by one until it reached the specified limit. The calibration process itself was repeated 3 times. The process of sting balance calibration is shown in Figure 12, and for the calibration result of the sting balance calibration is shown from Figure 13 up to Figure 15.

The characteristic of this sting balance is that when a load is given at the N1 position, it will produce a large amount of load at the N2 position. This characteristic is also applied when a certain amount of loads given at the N2 position; it will produce a large amount of load at the N1 position.

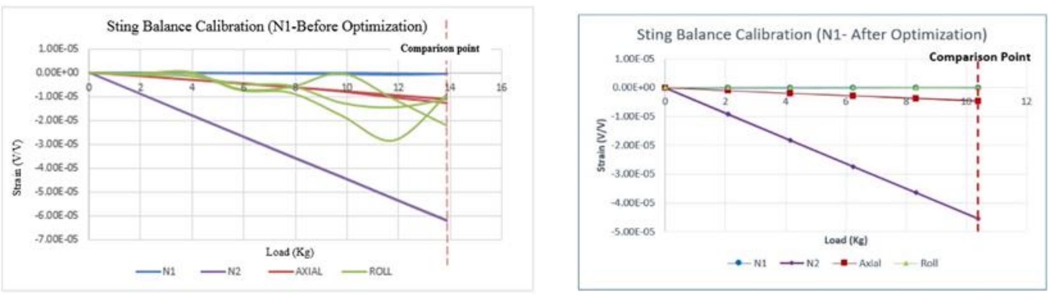

Figure 13. N1 calibration result (before and after optimization)

Figure 13 shows the calibration process with the load given at N1 position. From the maximum load point (red line dashed) it can be seen that the Roll value before optimizing the system is up to 35.6% of the N2 value with repetition measurement value which does not return at the same point. Meanwhile the calibration value after the system upgrading has a value at 0.039% from N2 value and the measurement repetition result is in the same line/point.

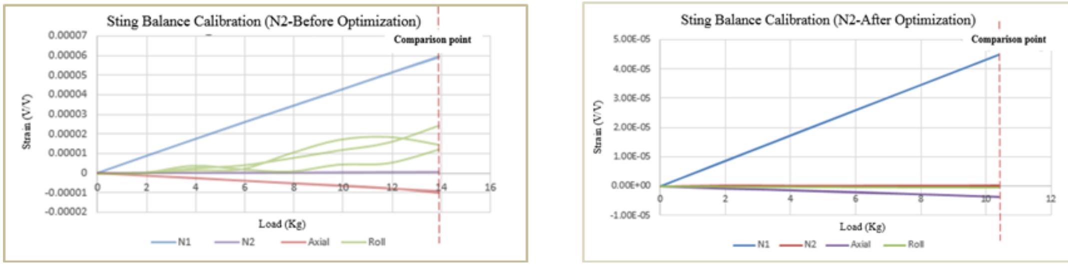

Figure 14. N2 calibration result (before and after optimization)

The same problem also occurs at the N2 calibration as shown in Figure 14; there are non-linear coupling effects at roll value and also at the repeated calibration, though the result is not in the same line. The maximum Roll value at maximum loading has a value of up to 40.7% of the N1 value, whereas the calibration process after upgrading shows the value of 1.35% of the N1 value and the results show the decreased coupling effects value.

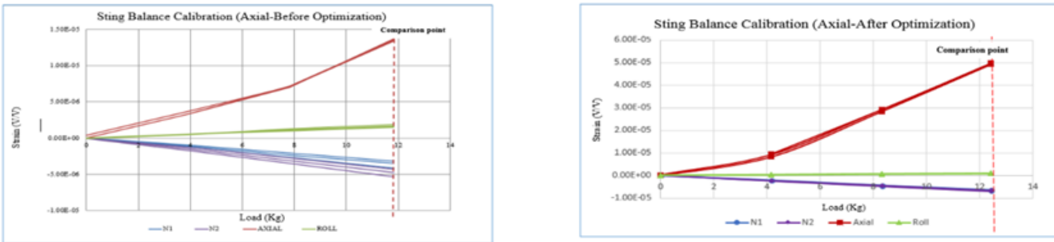

Figure 15. Axial calibration result (before and after optimization)

For axial calibration, as shown in Figure 15, there are values of Roll, N1, and N2. Even though it is linear, it has a poor repetition value. Likewise, the value of Roll, N1, and N2 is expected to be in the minimum if possible. The maximum Roll value before the optimization is 12% of Ax value and the calibration repetition almost gets in one line. For the N1 value at the maximum load, it has a value of 25% of the Ax value on the negative y-axis. As for the N2 value, it has a value of 39.4% of the Ax value, and the repetition of loading values recorded by the data acquisition; it is also not located in one line.

After the optimization, the maximum Roll value has decreased to 1.6% of the axial value, and the value of N1 has a percentage value of 12% of the axial value on the negative y-axis. As for the N2, it has a percentage value of 14% of the axial value.

The measurement repeatability for the N1, N2, and Roll values are all in one line at each value. As for the Axial value, there is still a slight difference in the repetition of calibration.

3.2. Control System

There are 2 things that are controlled in the supersonic wind tunnel control system; the sliding block and the angle of attack. As mentioned before, the angle of attack control uses the PID system and as for the sliding block control the mechanism is still the same. It is only digitalized using the PXIe from National Instrument [14].

- Angle of Attack Control System

The first step in making this system is to calibrate the angle of attack to the voltage reading. The results from the angle of attack calibration can be seen in Figure 16. The calibration result entered into the control program that had already created.

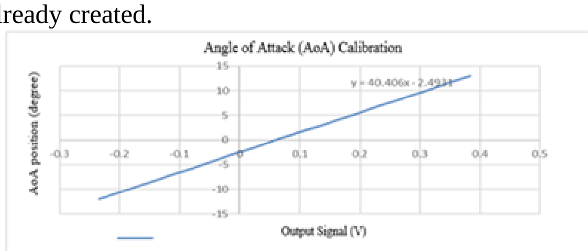

Figure 16. Angle of Attack calibration

Before the PID programming using LabVIEW begins, it is necessary to take the data from the angle of attack control system in an open loop. This data retrieval has been conducted by moving the sting balance manually (using switch and observation of position by the operator) as the PXIe system collected the data. From this data measurement, the response time from the minimum position to the maximum position of the output position can be seen. From Figure 17, it is known that the AoA control response time is almost linear but it appeared like a rising stepping ladder.

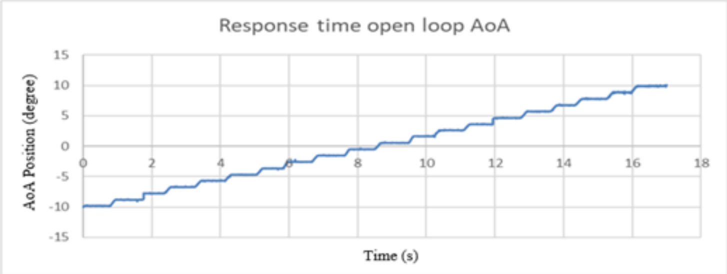

Figure 17. Open-loop AoA response time chart

So every 1 cycle, the gearbox moves 1 step. Because of that factor, the AoA open-loop response time cannot form a straight line. Based on the Ziegler-Nichols tuning method, creating a tangential line from the inflection point is a must. However, because the form of response time appeared like a ladder, the inflection point cannot be determined. From this finding, the search for PID gain is done by using the trial and error method.

At Figure 18, we can see that the AoA response with Kp = 0.05 is the closest to the setpoint and stop at the point set value. Ki value variation is also done with Kp = 0.05, however from the results obtained shows that there is oscillation at the set point. Based on the obtained Kp value, the next step to do is to test the response time and the accuracy of the sting balance position against the given setpoint value.

The response time test is conducted with a purpose of knowing the angle of attack response due to setpoint change. In addition, this test also aims to determine the accuracy of the angle of attack against a given set point.

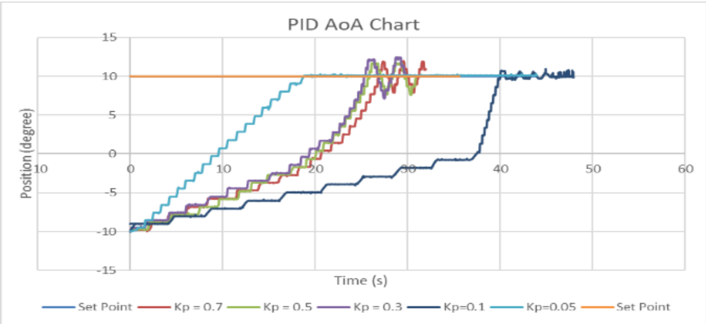

Figure 18. Kp variation for AoA control

From Figure 19, it can be seen that the PID system of angle of attack controls can respond well. For the accuracy of the angle of attack against the setpoint is good enough although there is still a difference of about 0.5^0.

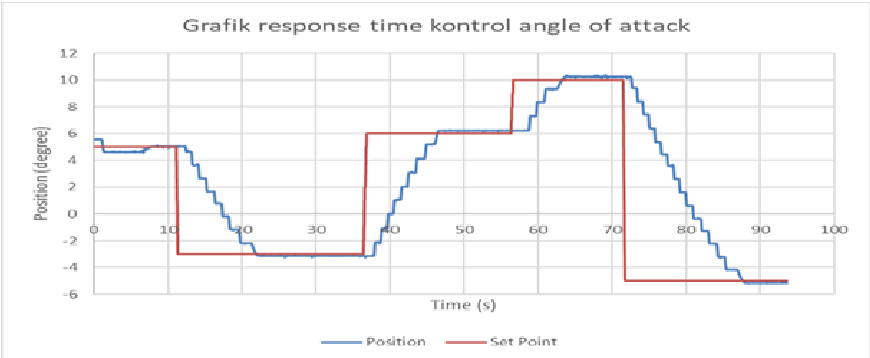

Figure 19. AoA Response Time

- **LabVIEW Program for Control System**

The Angle of Attack control system is basically using the PID toolkit provided in the LabVIEW [15]. Figure 20 shows that the operator only needs to enter the desired set point of angle of attack and after that press the OK button then the system will move the motor up to the desired set point position or until it reached the desired angle of attack position.

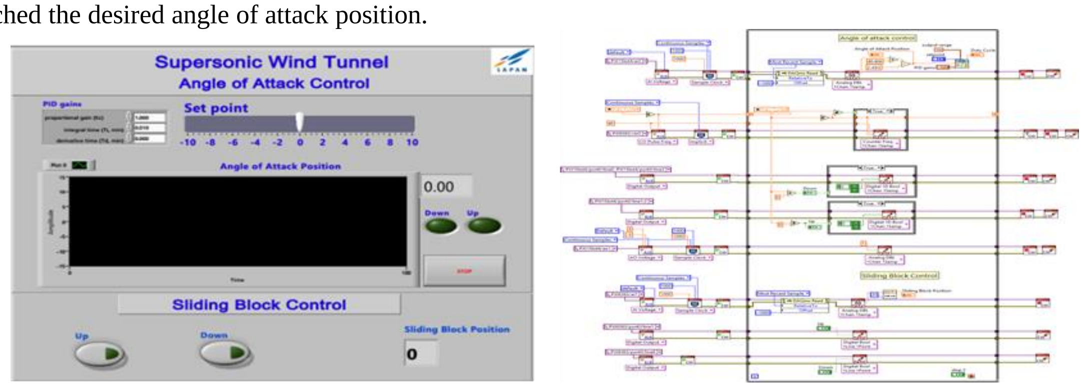

Figure 20. LabVIEW program for AoA and sliding block control

As for the block position control, the operator must see the last position of the block position then move the motor by clicking the + or - button on the software until it reached the desired set point.

- **LabVIEW program for data acquisition**

For the data acquisition system, as shown in Figure 21, it can be seen that there are graph displays to show the fluctuation of sting balance reading result; there is also display in numerical form. As for the pressure sensor readings, it can be seen on the 3 gauge display, in which each shows the value of static pressure, tank pressure, and total pressure.

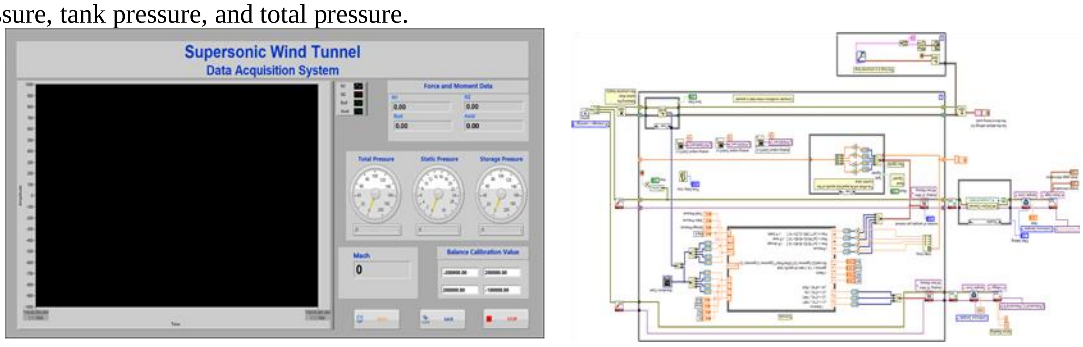

Figure 21. LabVIEW Program for data acquisition

4. CONCLUSION

On creating the angle of attack control system using the PID method, the results shown here are quite good. In this case, the automation on the angle of attack control has been achieved in which the operator's sole task is only entering the desired position value that will make the system runs by itself until it acquired the desired position. From the accuracy of achievement of the position, with the old system, there were errors up to 2^0, but with this new method in addition that the AoA control system using the PID system, the error decreased to 0.5^0. This shows that the design of system design in this research is a success.

There is a reduction in the interference/disturbance on sting balance system measurement/calibration results at the point of N1, N2, and Axial after the system optimization. The repetition data that are not in uniform and has relatively high fluctuations in Roll value specifically improved. Whereas the N1 calibration, the Roll value has a maximum load reaches 35.6% from N2 value and becomes 0.039% from the value of N2. In the N2 calibration, the Roll, which has a value of 40,7% of the N1 value, now become 1.35% of the N1 value. Subsequently, for the axial calibration, the Roll value at maximum loading is 12% of axial value, N1 value is 25% of Axial value on negative y-axis, N2 value is 39.4% of axial value and data repetition not yet on one line. After the optimization the Roll value decreases to 1.6% of the Axial value, the N1 value becomes 12% of the Axial value, the N2 value becomes 14% of the Axial value, and the repetition of the calibration data is already at one point for each value.

As a result of the new automated angle of attack system, it becomes possible to do various angles of attack while doing the testing. In the old system, it was not possible to do this kind of testing using this system because of the manual angle measurement and adjustment.

From the points above it can be concluded that the purpose of this research is the optimization of the instrumentation system consisting of upgrading the angle of attack control from the manual control to the automatic control. Other things gained in this research are the difference of the angle difference which has become smaller, the data acquisition system can get data that has a smaller interference, the data fluctuations that occur in the roll value have also been decreased and the repetition of data measurement of sting balance can be achieved. Finally, the results shows all systems are either Angle of Attack control or block position control, and the data acquisition system for sting balance and the data acquisition system for pressure transducer became one integrated system.

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