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THE DATA ACQUISITION ROLE ON STATIC TEST FOR VALIDATION OF RX320 ROCKET MOTOR DESIGN

Setiadi, Bagus Wicaksono*, Kurdianto, Bagus H. Jihad

Lapan Pusat Teknologi Roket Jl. Raya Lapan No. 2 Desa Mekarsari Kecamatan Rumpin, Kabupaten Bogor, Jawa Barat, Indonesia

*Corresponding Author Email: bagus_wicaksono2002@yahoo.com

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ABSTRACT

Data Acquisition System has a significant role, especially in static testing of a rocket, determining whether a rocket is declared eligible to fly or not based on the static rocket test. Static testing of the RX320 rocket involves several numerical data instrumentation components, including the Yokogawa DL850 and the CDA900 Signal Conditioner, and the PT750 Pressure sensor. It has functions to accept the physical force that occurs, measure and record the value of the Pressure force in the RX 320 Rocket Chamber at the time Static test during burning time is performed. From the record value of the RX 320 chamber pressure, it can be stated that the RX 320 is suitable for the rocket flight test. The calculation results of the chamber pressure design and the results of measurement and recording of RX320 static test data indicate that the Pressure Chamber RX320 value is still within the safe limits of the RX320 Rocket motor tube material strength.

Keywords: data acquisition, numerical data, RX320 statical test, rocket flight test

INTRODUCTION

1.1 Literature Review

Data acquisition is commonly used in many fields. In medical and health care, data acquisition is utilized to acquire the medical records of a patient [1].

In the industrial field, particularly in the manufacturing division of the factory, direct data acquisition is used to record the quality of components utilized in the electronic production process, mechanical process, or automotive production [2,3].

One of the advantages of a data acquisition system is its ability to trace the history of a specific case so that the history of a case can be searched when needed from a saved data record [4,5,6]. In rocket science and engineering, data acquisition is also harnessed and has a significant role for validation and analysis to determine the flight performance of a rocket. Then, the research process will become more efficient with the data acquisition system if the analysis of former rocket performance data is needed. Besides that, the data acquisition system can help the rocket designer validate rocket thrust of specific motor rocket design. In rocket RX320, data acquisition is used for static testing to measure and record potency and performance of flight using two parameters, namely, rocket thrust and pressure of the combustion chamber during the combustion process.

Rocket technology field nowadays can be remarked as has been in the advanced phase or stage and becomes one of the technology fields that has become a technological competition of many countries. Indonesia has owned RX320 rocket. Ballistic rocket type RX320 with a total length of 6236 mm, total mass of 1500 kg, maximum thrust of 9184 kgf, and uses solid propellant fuel. Before this rocket was finally flown, that rocket has passed a static test to know the quality, potency, and performance of its combustion. During a static test, numerical data from several parameters were measured and recorded [7]. Typical parameters that would be recorded is Thrust and Chamber Pressure. To measure and acquire numerical data, it is essential to provide a reliable data acquisition system. CDA 900 is used as a signal conditioning device and as output voltage conditioning that will be transmitted to the Pressure and Thrust sensor to acquire this numerical data. This signal conditioner's usage makes the data acquisition system stable and reliable up to 2000 m distance without any drop voltage than a direct data acquisition system without using a signal conditioner. The data acquisition system is represented by a block diagram, as shown in FIGURE 1.

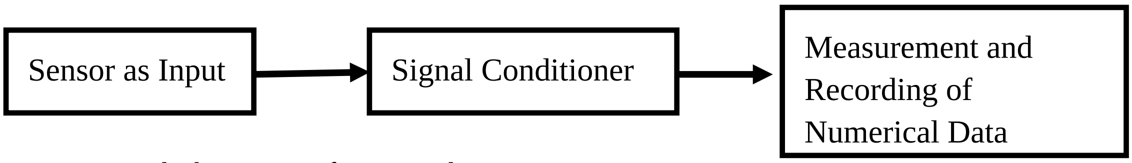

FIGURE 1. Block Diagram of Numerical Data Acquisition

The sequence of that numerical data acquisition is strain sensor type firstly senses physical force value. This value will be transmitted to the signal conditioner to be recognized and shown its value in the voltage unit. This unit is then shown to Numerical Data Measurement

Instrument and Recording Instrument to change that voltage unit to the desired unit, which corresponds to the needs of the recording instrument operator. Using this Signal Conditioner, the force of the Thrust value and the Chamber Pressure value become valid even though the measurement distance is up to 200 meters. The technology of this RX-320 payload during flight is also improved with the availability of pressure sensor and thermal sensor which not available yet at RX-320 payload of the fiscal year 2016.

1.2 Introduction of Rocket Motor Static Testing

In a rocket topic, static testing is needed as the step of rocket performance checking, either in terms of numerical data or in terms of visual data during combustion. One of the reasons static testing is conducted is to know the strength of structural mechanics with the effect of static thermal stress on the material and verify the rocket structure's design [2,3]. Static testing is a test to evaluate the quality of tubes used rocket motor or other components, where the testing object is ignited and exposed to heat and abrasion because of the combustion of its solid-propellant during combustion time. Its pressure is increased to reach a specific pressure value. Then the testing object is measured and recorded using a data acquisition system during a specific duration to determine the strength of the material as a result of high-pressure loading until near the material strength limit. This testing is conducted on the pressure under the normal working condition of a test object. In the context of the rocket motor tube, this test aims to determine the strength of the motor tube under thermal loading and pressure from inside of the motor tube. Static testing is essential for testing the motor rocket tube made of a factory that may be different in material characteristics from the previous factory. The structure of the rocket tube must have a characteristic strong enough to withstand internal pressure resulted from the combustion of solid propellant. Therefore, in its design, the rocket motor tube needs to be calculated thoroughly and also needs validation by testing its strength [8]. In this static testing, the pressure parameter is measured, but the thrust produced by the rocket motor is measured. Both of them influence the material of tube structure. Meanwhile, other parameters measurement, such as strain, will be conducted on other testing and different discussions.

RX320 rocket is a rocket with a length of 6236, a diameter of 324 mm, and a booster of a multi-stage rocket [9] whose mission is to deliver the satellite to orbit up to 1000 km from the surface of the earth. Rocket motor that has passed the static testing step can undergo the following testing step: flight test. In FIGURE 2, the static test of a rocket motor is shown.

FIGURE 2. Static Test of Rocket Motor (Static Fire Test)

1.3. Components of Numerical Data Recording Instrument

As mentioned in the previous section about static testing which involve data acquisition system with very important function for measuring and recording phisical phenomena during rocket combustion time [10]. There are many brands of data acquisition devices in the market. One of them is Yokogawa DL850. There are 16 channels of analog inputs I/O in this Yokogawa DL850 which means it can measures, record, and shows 16 input of analog data at the same time. There are also some features in this Scopecorder, such as big storage capacity Hard Drive up to 200 Gb, data processing from graphical numerical data recorded, internal printer, and so forth. However, this scope order also has a few limitation, for instance, vertical and horizontal limit value which has a maximum of 10 division. If measuring duration exceeds ten divisions, the values that exceed the last division will not be recorded.

Another device also assists this data acquisition instrument: signal conditioner CDA 900, which has the function to provide excitation voltage to the sensor so that the sensor can transmit the phenomena that it senses to the signal conditioner device. Moreover, the signal conditioner also functionates to stabilize the signal from the sensor. Then, that signal is recorded by data acquisition instrument Yokogawa DL850 with the unit converted and fit with the operator's need.

1.4 Design of Rocket Motor Tube

A static test of rocket motor RX320 was conducted on December 22nd, 2019, with good results. One of the benchmarks is the safe tube; no crack found. Rocket motor tube is an essential component in rocket motor because it contains rocket fuel, which produces thrust. This tube must withstand pressure loading from the inside (internal pressure) high enough from the rocket [11]. Besides that, the tube must withstand force come from the pressure on the cap structure part and nozzle part.

The shape of the tube is a cylinder with one end is covered by the cap and another end is mated to the nozzle. The length of the rocket motor is 4220 mm; outer diameter is 324 mm, and thickness is 4 mm; look at FIGURE 3 below. The material of the tube is steel with series KH406. Properties data of material is obtained from the vendor. Then the testing is conducted to obtain tensile strength by static tensile test. To know the strength of the rocket motor while the flight test is conducted, the static test must be done beforehand. Output from the static test, mainly internal pressure, is used to analyze whether the material of the tube is still strong or not and as a reliability indicator of tube structure design.

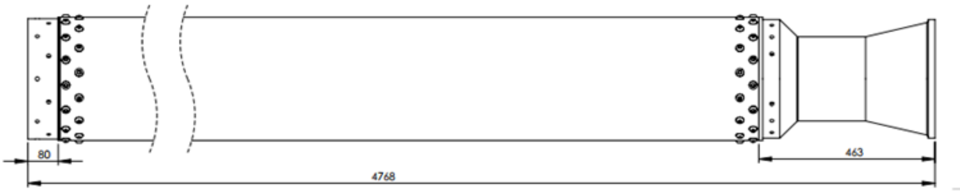

FIGURE 3. Technical Drawing of Rocket Motor of RX320

METHODOLOGY

2.1. Input, Process, and Output of Testing Instrument

A data acquisition system consists of more than one component. Moreover, from that system, it is expected that there is output, namely numeric data from which the analysis to determine whether the performance of rocket motor design corresponds with absolute rocket or not, is conducted. Therefore, to be able to produce that numerical data output, then a data acquisition system needs input that has bias come from the sensor that can sense value or physical force of rocket motor during a static test. To produce the output, the input must be processed by a signal conditioner and acquisition data device. The process as follows: Input in numerical data of specific force from the sensor is measured then recorded by the acquisition data device. This input will have data resolution that can be adjusted with the operator's need and adjusted with a resolution data limit of the data acquisition device. As mentioned in another Manuscript [4,12], real-time data acquisition is used to build a monitoring system such as a liquid volume monitoring system.

2.2. Output and Its Application

As mentioned in the introduction section about how data acquisition works, start from measuring until recording the value of physical force value. Yokogawa DL850 is used as a numerical data recorder in more specific instrumentation that can be adjusted on several physical force units.

Before an acquisition data device is used to measure and record the physical parameter of a tested rocket, calibration is conducted using a calibrator to correct the setting and adjustment of the data acquisition device. This process will ensure that the parameter measured will have the correct value when the device is used to measure physical force by connecting the data acquisition device to a specific sensor. The number of calibrations is as much as the amount of the sensors or parameters used in a static test.

A data acquisition system is a particular electronic device with the computer as the data processor and all hardware and software inside of it that often used and reliable to synchronize input current flow from the sensor (physical force) that will be recorded in its internal storage as numerical data.

There are two parameters from static test output, namely thrust and internal pressure. Thrust is used for rocket flight dynamics, aerodynamics, and propulsion system performance, while internal pressure is used for rocket motor structural strength control, in this case, is tube material of rocket motor [9].

2.3. The Reliability of Rocket Motor Tube Design

The reliability of rocket motor tube design is determined from an analytical and numerical calculation using a datasheet of material used [13]. In order to make the data to be more valid, the material data used should be based on material strength tests. One of them is the static tensile test.

Besides that, the reliability of the design of a rocket motor is also determined from the static test result of a rocket motor, whether by visual there is a failure phenomenon from combustion or leakage in the tube during the burning time of rocket motor. Numerical data value recorded in the acquisition data device is used as a working load, which can be in the form of internal pressure in the tube. Then thrust data that work on rocket motor.

The tube's material strength analysis is needed to provide mechanical, technical data, physical data, and thermal data. Furthermore, data on tube dimensions are also needed. The calculation of structural analysis is needed to know how much stress will occur in the tube. The stress that will occur on the material must be less than the strength of the material, which can be obtained from the static test result of the material sample.

RESULTS AND DISCUSSION

3.1. Result Data of Motor Static Test

As explained in the previous section about the function of the data acquisition system, that is to provide validation and judgment of a rocket motor RX320 about its design's reliability status to conduct the next step, namely flight test.

It also had been explained in section 2.2 that there are two parameters of the static test: thrust and internal pressure or combustion chamber pressure. Thrust is used for rocket flight dynamics, aerodynamics, and propulsion system performance. Meanwhile, the internal pressure is used for controlling the structural strength of the rocket motor. In this case, it is the tube material of the rocket motor.

From FIGURE 4 below, it is shown that the maximum thrust is 9184 kgf and the average thrust is 6796 kgf with a burning time of 11.68 seconds.

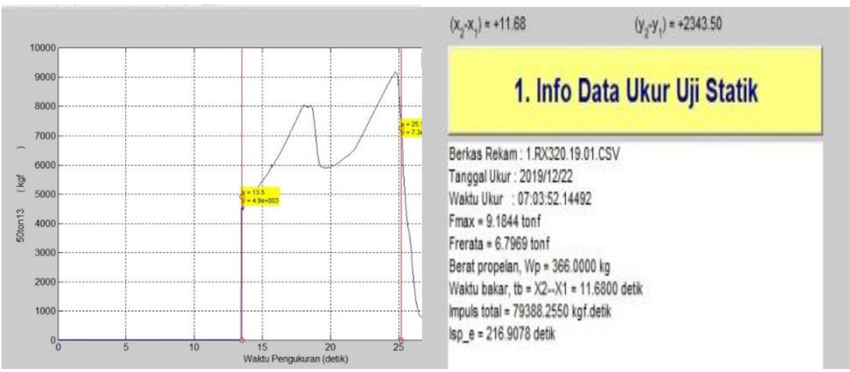

FIGURE 4. Numerical Data Acquisition Result of Thrust from Static Test of RX320.

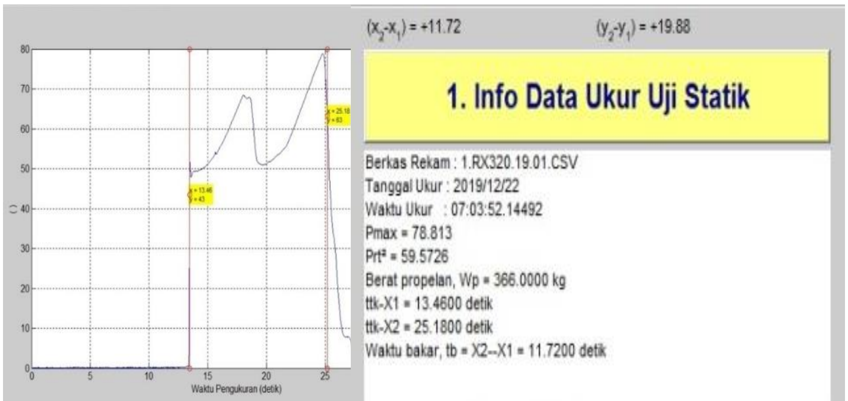

FIGURE 5. Numerical Data Acquisition Result of Combustion Chamber Pressure from Static Test of RX320.

From FIGURE 5, the static test result shows that the maximum value of combustion chamber pressure of RX320 is 78.8 bar, whereas its average value is 59.57 bar with a burning time of 11.68 seconds. This 78.8 kg/cm^2 pressure data is used as work loading calculation. In design, the value of work loading is assumed as p = 100 kg/cm^2.

In the previous activity result before using the signal Conditioner CDA900 (before period 2017 fiscal year), the value of Thrust and Pressure chamber is often experiencing the sensor output voltage losses of about 5 to 10% during the burning time due to the length route of data acquisition reach up to 200 meters which directly will affect to the drop of measured thrust and chamber pressure value.

3.2. The Data of Material Test Result and Others Technical Data

In this section, the focus will be on data of rocket motor tubes with a cylindrical shape. The length dimension of the tube is 4220 mm, the outer diameter is 324 mm, the thickness is t = 4 mm, and the radius is r = 16 cm. The tube is made of steel with KH406 series, wherefrom factory certificate that we have received, the tensile strength value is 1620 MPa, and the yield strength value is 1320 MPa [14]. Then from the tensile test result conducted in B2TKS Puspiptek Serpong at the late-year 2016, the magnitude of tensile strength of the steel is σ_u = 1497.5 MPa or equivalent with 15260 kg/cm^2, and the yield strength of steel is σ_y=1220 Mpa or 12434 kg/cm^2. Next is the value of material strength that is used based on the material test in B2TKS Puspiptek. The output of static test, especially internal pressure, is needed to analyze whether the material of the tube is still strong and as an indicator for reliability of tube structure strength design [15].

Other technical data that needed are:

Modulus of Elasticity of Material = E = 2,100,000 kg/cm^2.

Poisson's ratio = μ = 0.3.

The difference between outer wall temperature and inner wall temperature = Δt, the value of Δt is taken from simple measurement = 100^{0}C.

Linear Expansion Coefficient = α = 12 x 10^{-6} / ^{0}C.

3.3. Discussion and Result Processing

At enough distance from the end of the covered cylinder, the theory of thin-shell structure or thin-membrane is accurate enough. Cylinder with the radius r results in the stress with axial longwise direction represented by σ_x, and with a hoop or circular direction represented by σ_h, respectively can be calculated by the formula:

$$\sigma_x = p.r/(2.t) \text{ and } \sigma_h = p.r/t \quad (1)$$

From the same reference, if the stress of the membrane is the only parameter that is calculated, there will be discontinuity on the connection area between the tube and the cap (tube cover). However, the practical concept will be used, from which it can be concluded that in most cases, σ_x will increase 30% on the connection area, while σh will be relatively the same.

Thus, the maximum bending stress that work on the tube are:

Axial longwise stress σ_x= 1,3 p.r/(2.t) = 2600 kg/cm^2

Hoop direction stress σ_h= p.r/t = 4000 kg/cm^2

The combination of both stress from which the Von Misses stress is obtained can be calculated as follow:

$$\sigma_{vm} = (\sigma_x^2 + \sigma_h^2 - \sigma_x . \sigma_h)^{1/2} = 3842 \text{ kg/cm}^2 \quad (2)$$

This stress combination (σ_{vm}) represents the failure criteria of structure.

As remarked above, the thermal load can be minimized by applying a thermal protection layer that is good enough for the tube. Furthermore, the thermal stress that works on the tube will be described modestly, which is a scale that depends on the difference of temperature on the wall Δt, the coefficient of linear expansion α, the modulus of elasticity E, and Poisson's ratio μ.

Assumed that the temperature variation that passes through the thickness direction of the tube is linear, and the temperature is homogenous on the plane parallel with the surface of the tube [15], then the value of the stress from the temperature effect is:

$$\sigma_{th}= \alpha. \Delta t .E / 2(1- \mu) \quad (3)$$

By assuming the parameter above, the thermal stress can be obtained with the magnitude σ_{th} = 1800 kg/cm^2.

Total stress that works on the tube is the addition because of the combination between bending and thermal stress = $\sigma_{vm} + \sigma_{th} = 5642$ kg/cm^2.

3.4. The Discussion of Result as Structure Design Reliability

In the preliminary design, the strength of the tube is based on the internal pressure that is produced on the rocket motor static test (static fire test). The output from the static test, mainly internal pressure, is used to analyze whether the material of the tube is still tough and used as an indicator of the reliability of the tube structural design.

The recorded data from the static test shows that the internal pressure has a magnitude of 78.8 kg/cm^2. On the other hand, the pressure magnitude used for calculating the working load is set to 100 kg/cm^2.

From that magnitude, the analytic calculation will result in the total stress working in the tube $\sigma_{vm} + \sigma_{th} = 5642$ kg/cm^2, which is the addition of bending stress and thermal stress. Next, from the static tensile test of material, the magnitude of yield strength, σ_y= 12434 kg/cm^2, is taken and will be compared with von misses stress as material failure criteria.

Thus, the safety factor of design SF = 12434/5642 = 2,2. The value of that safety factor is reliable but less economical. In that case, this material can still be used for bigger tube diameter (e.g., 450 mm diameter), or one of the other choices is to use material with a lower grade.

Selain itu berdasarkan pengamatan secara virtual, ketika uji statik motor roket berlangsung, tidak terjadi kebocoran atau keretakan pada struktur motor roketnya. Hal ini berarti desain sambungan dan isolator penahan panas bekerja dengan baik.

Besides that, according to the experience virtually, when the static test of the rocket motor is in the process, there are no leakages or cracks on the structure of the rocket motor. This means that the design of the connection and thermal protection isolator is working correctly.

CONCLUSION

From the description in the previous section, where the safety factor of material with the working load from the static test is 2.2, it can be concluded that the design of the rocket motor tube is safe for the next test, namely flight test. With the same material, the higher diameter of the tube can also be applied. There are no leakages or cracks on the tube, which means the design of the connection and isolator is proper and reliable. The simulation or numerical calculation is required as a comparison from the analytical calculation. Data acquisition system has an essential role in validating the value of the measured parameter which has been specified in the design stage. Thus if the result from data acquisition shows that the value of parameter designed is not proper with respect to the static test, then a rocket cannot yet be justified as ready status, and reliable for the next step, that is, flight test.

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REFERENCES

[1] Kugelstadt, Thomas, "Industrial Data Acquisition Interfaces With Digital Isolators," 2011.

[2] Alfredo *et al.*, "Structural Health Monitoring for Advanced Composit Structure," *Journal of Composite Science*, vol. 4, p. 13, 2020.

[3] Setiadi, "Hasil Uji Tarik Bahan Stainless Steel 17-7 PH Sebagai Validasi Kekuatan Tabung Motor Roket RX-550 LPN Terhadap Beban Internal Pressure dan Thermal Pressure," Prosiding Seminar Nasional Perkembangan Riset dan Teknologi di Bidang Industri ke-17, Yogyakarta, 16 Mei 2015, ISBN : 978-979-95620-7-4.

[4] M. Feuntes *et al.*, "Design of an accurate, low-cost autonomous data logger for PV monitoring using Arduino that compiles with IEC standards," *Journal of Solid Energy Materials and Solar Cells*, Elsevier, pp. 529-543, 2014.

[5] A. Gonzalez, J. L. Olazagoitan, and J. Vinolas, "A Low Cost Data acquisition System for Automobile Dynamic Applictions," *Journal of Sensors (MDPI)*, pp. 1-20, 2018.

[6] Ott, Dylan Allan, " The Design of Rocket Propulsion Labview Data Acquisition and Control System," 2018.

[7] K. Maes *et al.*, "Online Synchronitation of Data Acquisition System Using System Identification," *International Journal of Sound and Vibration*, 2016.

[8] Eren, Halit, "Data Acquisition Fundamental," Process Software and Digital Network, *Journal of Instrumentation Engineer*, pp. 330-341, 2012.

[9] Martins, Christiane Aparecida, "Development of Test Stand for Experimental Investigation of Chemical and Physical Phenomena in Liquid Rocket Engine," 2011.

[10] Bidang Teknologi Struktur dan Mekanik Pustekroket, "Desain Teknik Struktur Motor Roket RX320," 2014.

[11] Suksila, Thada, "Experimental Investigation of Solid Rocket Motors for Small Sounding Rocket," 2018.

[12] Pratiksha Sarma, Hidam Kumarjit Singh, Tulshi Bezboruah, "Real Time Data Acquisition System for Monitoring Sensor Data," International Journal of Computer and Science Engineering, vol. 6, 2018.

[13] Freeman, Charles, "Solid Rocket Motor Static Fire Test Stand Optimization: Load Cell Effect and Other Uncertainties," 2018.

[14] Dalian Chlorate Co. Ltd, "KH 406 China Xi-An aerospace chemical propulsion plant: certificate of origin mechanical performance," size tube, 2016.

[15] Balai Besar Teknologi Kekuatan Struktur Puspiptek, "Laporan Teknis Uji Tarik Material Tube," Desember 2016.