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Y-1399

Nuclear Reactors for
Rocket Propulsion

OCT 1 1982

AEC RESEARCH AND DEVELOPMENT REPORT

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CRD
10/18/77

AIR FLOW INSPECTION OF ROVER FUEL ELEMENTS

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Date Issued: September 28, 1962

Report Number Y-1399

Nuclear Reactors for Rocket Propulsion
M-3679 (26th Edition)

UNION CARBIDE NUCLEAR COMPANY
Division of Union Carbide Corporation

Y-12 PLANT

Contract W-7405-eng-26
With the U. S. Atomic Energy Commission

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Classification cancelled (or changed to) Dec C
by authority of A7C TIC, date AUG 30 1973
Exempt from CCRP Re-review Requirements
(per 7/22/82 Duff/Caudle memorandum)
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ABSTRACT

Improvements were required in the precision of the air flow inspection system of Rover fuel elements. Two systems have been constructed which use strain gage pressure transducers to monitor the changes in static pressure caused by changes in hole diameters. One system uses a strip-chart recorder as a readout device and has a precision of ± 0.0001 inch; a second system has a digital readout and card punch. This latter system has a precision of ± 0.00007 inch and eliminates the recording of data by hand.

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INTRODUCTION

Certification of the Rover Type B-1 fuel elements requires measurement of the gas passage diameters and "within element" diameter variations. This inspection is based on the measurement of static pressure at the injection nozzle of a constant flow-rate air stream as it is discharged through the gas passage. Static pressure is related to diameter by using precision-drawn stainless steel tubes as calibration standards. An existing system using a Sheffield Precisionaire did not have the necessary precision. Production and inspection tolerances for the fuel elements required a system that would yield an air flow diameter with a precision no worse than ± 0.0001 inch.

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SUMMARY

Two inspection systems have been constructed which use strain gage pressure transducers to pick up changes in static pressure due to changes in the hole diameter. These two systems differ in the type of readout devices that are used and have slightly different air supplies. In the first system the signal from the transducer is fed into a recorder which has zero suppression and span adjustment. The pressure in the supply line is regulated by a precision regulator which appears to act as a critical flow orifice, producing a constant mass flow system. The results of a test indicate that the precision of this system is ± 0.0001 inch. The second system uses a critical flow nozzle to maintain a constant mass flow system. The output of the transducer is amplified and displayed on a digital voltmeter. The signal from the voltmeter is fed into a digital converter and then to a card punch. This system is capable of printing five digits after the decimal and the precision is approximately ± 0.00007 inch.

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DISCUSSION

INTRODUCTION

Final inspection of Rover fuel elements consists of an air flow measurement which is related to the diameter of the gas passage holes. Inspection personnel are interested in the relative flow diameter of the fuel elements as compared to the diameter of standard drawn stainless steel tubes. For the elements with seven uniform holes, the requirements are that the deviation from the average flow diameter of the seven holes must be no more than ± 0.0005 inch. This requirement necessitates an inspection system which has a precision of at least ± 0.0001 inch. The original inspection system made use of a Sheffield Precisionaire column and pneumatic amplifier which was calibrated by use of drawn stainless steel standards, but this system did not have the precision that was needed.

AIR FLOW SYSTEM USING A STRAIN GAGE PRESSURE TRANSDUCER

A system was constructed which made use of a full bridge strain gage pressure transducer with a 12-volt regulated DC power supply. Figure 1 is a block flow diagram of the system. This system detects the static pressure at the injection nozzle (see Figure 2) and converts it to an electrical signal. Variations in diameter of the gas passage holes show up as variations in the static pressure reading. A strip-chart recorder with zero and span adjustment is used to display the electrical signal. The static pressure does not change in a linear manner with changes in hole diameter and, for this reason, the system must be calibrated over each 0.005-inch range of hole sizes. The pressure in the supply line is regulated by a precision pressure regulator which seems to operate also as a critical flow device, producing a constant mass flow system. The regulator is set to produce a static pressure of approximately 11 psig at the injection nozzle when discharging into the 0.1455-inch-diameter standard. As in the original system, drawn stainless steel tubes are used as standards of calibration.

An experiment was designed to determine the precision of this flow measurement system. The experiment consisted of the measurement of two carbon holes and four stainless steel standard holes. The six holes were measured twice by two inspectors at three different times beginning three hours apart. Results of the experiment are as follows:

1. The precision appears to be better than ± 0.1 mil.
2. The difference between the two inspectors is negligible.
3. There was relatively little variation between the times at which the holes were measured.

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Figure 1. AIR FLOW INSPECTION SYSTEM AND STRIP CHART RECORDER.

Figure 2. INJECTION NOZZLE.

AIR FLOW SYSTEM USING A CRITICAL FLOW NOZZLE

A second air flow system has been developed and constructed which uses a critical flow nozzle to produce a constant mass flow system, and a digital voltmeter and card punch as readout devices, as shown in Figure 3. Performance evaluation tests indicate a precision of approximately ± 0.00007 inch. Figure 4 is a block diagram of the digital air flow diameter gage. In this system, a precision regulator is used to maintain the supply pressure to the critical flow nozzle, and this regulator is adjusted to give the desired static pressure at the injection nozzle. As in the previous system, the transducer output is a DC millivolt signal proportional to the static pressure. Signal inversion and suppression are provided by a variable signal bias supply.

Signal inversion is required because the static pressure is an inverse function of the diameter. Figure 5 is a graph of the transducer output signal as a function of the gas passage diameter. Proper adjustment of signal amplification and zero suppression provides a direct digital voltmeter indication of diameter. This voltmeter indication system is capable of reading five decimal places; however, it has been adjusted to read and print four decimal places. The calibration range for this system should be approximately 0.005 inch.

The inspection system using a recorder requires two inspectors; one for operation and another for manually logging the diameters. Also, the data are transcribed to punched cards for automatic data reduction. The digital system requires a single operator and the punched card output is directly compatible with automatic data reduction procedures.

STANDARDS PROCUREMENT AND MEASUREMENT

Since the absolute accuracy of these two inspection systems depends upon the standards used for calibration, it was necessary to obtain standards which had accurately known diameters. At Y-12, the diameter of the stainless steel standards was determined by air probe measurement at 25 locations along the length of the tube. The average of these measurements was taken as the true diameter. Air-flow readings on these standards were then obtained using the digital air flow diameter gage. The static pressure was approximately 14.5 psig when discharging into the smallest standard and the span adjustment had been set to maximum sensitivity. A best-fitting calibration curve was calculated for the data points and the diameters of the standards reassigned to fall on this curve. Table 1 shows the results of this procedure while Figure 6 is a plot of the standard diameter versus voltmeter readout at four different pressure levels.

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Figure 3. DIGITAL AIR FLOW DIAMETER GAGE.

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Figure 4. DIGITAL AIR FLOW DIAMETER GAGE. (Block Diagram)

Figure 5. PRESSURE TRANSDUCER OUTPUT vs GAS PASSAGE DIAMETER.

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Table 1
Y-12 STANDARD DIAMETERS

Tube Number	Air Probe Diameter (mils)	Estimated Standard Value ± LE of the Calibration (mils)
1	145.7	145.90 ± .09
2	145.8	145.78 ± .09
3	149.0	148.96 ± .09
4	151.4	151.46 ± .09
5	153.2	153.28 ± .09
6	154.3	154.19 ± .09
7	155.6	155.69 ± .09
8	155.8	155.78 ± .21
9	155.9	155.87 ± .21
10	156.6	156.41 ± .21
11	157.0	157.14 ± .21
12	161.7	161.87 ± .21
13	164.1	163.92 ± .21
14	165.6	165.62 ± .13
15	165.9	165.76 ± .13
16	169.5	169.56 ± .13
17	169.8	169.98 ± .13
18	173.7	173.63 ± .13
19	175.5	175.46 ± .13

Figure 6. VOLTMETER READOUT vs STEEL STANDARD DIAMETER.

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Although the repeatability of measurements was felt to be most important, a study of the accuracy of standards was made. Three independent techniques were used to establish the effective diameters of a set of stainless steel tubes. These were: (1) air probe, (2) gravimetric, and (3) laminar flow. Air probe measurements were made at Y-12 as described previously. The gravimetric diameters and the effective diameters from air flow data at low Reynolds numbers were measured by the Physical Measurements Department at the ORGDP. The laminar flow equations which are only valid at low Reynolds numbers were used to calculate the flow diameters. Table 2 lists the results of these procedures. A comparison of the results indicates the following:

1. Y-12 results averaged 0.011 ± 0.063 percent higher than the gravimetric data; an insignificant difference.
2. Laminar flow results averaged 0.141 ± 0.090 percent higher than the gravimetric data.

Figure 7 shows the techniques used in this comparison. Y-12 air probe measurements agree with the very precise gravimetric results to less than two hundredths of one percent so that either method would be satisfactory for establishing standard values on the hole diameter.

At the present time the inspection system using the recorder as a readout device is used for the final air flow inspection. The digital system is being used for preliminary inspection after the reaming operation. Use of the digital system is being considered for the final inspection of future reactors.

Table 2
AVERAGE DIAMETERS OF STAINLESS STEEL TUBES

Tube Number	Y-12 ⁽¹⁾ Diameter	ORGDP Diameters ⁽²⁾			
		Gravimetric		Laminar Flow	
		Mean	95% Confidence Level	Mean	95% Confidence Level
1	145.5	145.46	0.03	145.5	0.1
2	148.0	147.79	0.02	147.8	0.2
3	149.0	149.40	0.02	149.6	0.1
4	151.6	151.82	0.02	152.0	0.1
5	154.1	153.92	0.02	154.4	0.1
6	155.9	155.65	0.02	156.1	0.1
7	158.2	158.38	0.01	158.6	0.1
8	161.3	161.75	0.03	162.1	0.1
9	161.9	161.83	0.02	161.7	0.1
10	164.0	163.99	0.02	164.1	0.1
11	165.8	165.51	0.01	166.1	0.1
12	168.9	168.82	0.03	168.9	0.2
13	170.0	170.03	0.02	170.3	0.1
14	171.9	171.73	0.02	171.8	0.2
15	174.0	173.83	0.01	174.6	0.2
16	175.5	175.43	0.01	175.9	0.2
17	178.6	178.51	0.01	178.3	0.4

(1) Air Probe Diameter

(2) All diameters and confidence levels are expressed in mils

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Figure 7. COMPARISON OF Y-12 AIR PROBE AND ORGDP FLOW DIAMETER MEASUREMENTS WITH THE ORGDP GRAVIMETRIC MEASUREMENTS.

CONCLUSIONS

Two conclusions have been reached as a result of this study:

1. The improved air flow inspection systems, either with a chart recorder or a card punch for readout, have a precision no worse than ± 0.0001 inch.
2. The absolute accuracy of the flow diameters is dependent on the accuracy of the standards used for calibration. The agreement of Y-12 air probe and gravimetric measurements indicates that either method would be satisfactory for establishing standard values on the hole diameter.