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UNCERTAINTY OF MEASUREMENT OF TRANSIENT PRESSURE

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Abstract − The measurement of air shock wave pressure is a typical problem of transient measurement. Because the measurement data in many cases is used to judge the quality of a product, or as a basis for changes being made during a development phase, uncertainty analysis or assessment of measurement data takes a very important role in the process of reporting experimental results. It is very difficult or impossible for most transient measurements to be experimented repeatedly under the same condition, so their uncertainty analysis differs from the method of analyzing static measurement data. The paper gives several main components of uncertainty and their experimental data of the measurement system of air shock wave pressure, especially analyses and processes dynamic sensitivity and overshoot values of the system excited by step pressure signal which is generated by shock tube. The results of uncertainty analysis are presented. The method of dynamic uncertainty provides a kind of solution to analyze and assess the result of single measurement or a few measurements.

Keywords: transient pressure; measurement uncertainty

1. INTRODUCTION

Because the measurement data in many cases is used to judge the quality of a product, or as a basis for changes being made during a development phase, uncertainty analysis or assessment of measurement data takes a very important role in the process of reporting experimental results. However, according to the GUM method [1], many measurement systems are statically calibrated with evaluation of the measurement uncertainty. When dynamic or transient signal are measured, this kind of transducers with a bandwidth much higher than the signal intended to be measured is always selected in the first place in order to resemble static measurement. Despite that, the difference dynamic sensitivity differs from static sensitivity, and non-perfect dynamic response of measurement system will generate bigger uncertainty than the static errors. Without dynamic calibration no quantitative estimate of dynamic uncertainty of measurement system can be made. Other than static calibration, dynamic calibration is related to bandwidth of excitation signal. So, the frequency response function of measurement system is generally what people want to obtain, though the measurement error in the time domain can't be directly estimated by use of it. A kind of concept of dynamic uncertainty regarding operational frequency band-width of transducers and measurement systems was presented in order to choice appropriate dynamic measurement systems according to frequency spectrum of measured signals [2-3]. The uncertainty concept of frequency response of transducers or measurement systems was presented [4]. For dynamic or transient measurement, another considerable problem is that under the same condition it is very difficult or impossible for most of dynamic or transient measurements to be experimented repeatedly. So, their uncertainty analysis differs from the statistical method of analyzing static measurement data. A kind of novel calculating method of estimating maximum dynamic error was presented in the assumed condition of known transfer function [5]. But in reality, the estimation of transfer function is generally used instead of its ideal one. According to current level of measuring air shock wave pressure, the paper gives several main origins of the measurement error and their uncertainties, especially processes the difference between static and dynamic sensitivity based on experimental data, and the correction of overshoot values of the system based on multi-experimental results by use of step pressure signal generated by shock tube. The result of uncertainty combination using analysis is presented. The method of dynamic uncertainty is helpful to the solution to analyze and assess the result of single measurement or a few measurements.

2. SPECIAL MEASUREMENT SYSTEM OF AIR SHOCK WAVE PRESSURE

There are two categories of measurement systems of air shock wave pressure with time-varying at present. One category of them consists of sensor, long signal transmission cable, general amplifier, digital recorder or oscillograph, and power supply, etc. Its typical sketch map is showed in Fig.1 [6]. In practical measurement, only sensor, signal transmission cable and its fixing structure are exposed to the environment intended to be tested. Because of the long signal transmission cable, it is not neglected or difficult to estimate for the random noise of the system. At the same time, bigger signal-noise ratio makes against dynamic correction of the system. Another category is special measurement system, which integrates sensor, signal conditioning, controller, record memory, battery and power manager, interface circuit and shell with functions of protection and fixing, and so on. Its typical photograph is showed in Fig.2. This kind of system can be directly installed within the environment measured. Miniature technique and protection measure structurally are taken, signal-noise ratio of the measurement system is so smaller

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that it can be neglected. There are some other advantages such as special designing in term of user' requests, avoiding electromagnetic interference and so on. Aiming at this kind of typical measurement system implemented by our laboratory, the paper gives main origins of causing error and their uncertainties in following sections.

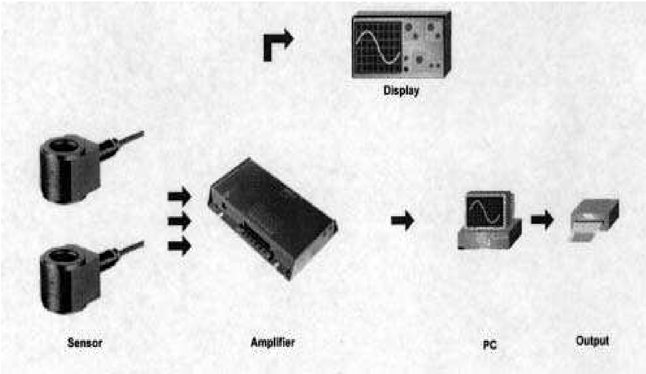

Fig.1 general structure of measurement system


Fig.2 photograph of special measurement system

3. EXPERIMENT AND CALCULATION OF UNCERTAINTY

Following uncertainties should be considered from points of experimental and metrological view in terms of the particularity of measuring air shock wave pressure.

3.1. Determination of Dynamic Sensitivity

the dynamic sensitivity of the system was experimented and determined by use of shock tube which is set up by National Key Laboratory of Electronic Test Technology. The shock tube is considered to be an idealized pressure step generator. According to shock tube theory, there are relationships as follows:

$$P_s = \frac{7}{6}(M_s^2 - 1)P_0$$

$$P_r = \frac{7}{3}(M_s^2 - 1)(\frac{4M_s^2 + 2}{M_s^2 + 5})P_0$$

Where, P_s —— the amplitude of the pressure behind the reflected shock wave encountered by a transducer mounted in the tube side-wall;

P_r —— the amplitude of the pressure behind the reflected shock wave encountered by a transducer mounted in the tube end-wall;

P_0 —— the amplitude of the pressure of gas in low pressure chamber;

M_s —— the shock wave Mach number.

The results of dynamic calibration are showed in table1. Its dynamic sensitivity and standard deviation is as follows:

$k_{dyna} = 2.043 \times 10^{-1}$ (MPa/V),

$\Delta k_{dyna} = 4.834 \times 10^{-3}$ (MPa/V)

If confidence level is 95%, then relative uncertainty

$$\delta_{dyna} = {2 \cdot \Delta k_{dyna}} / {k_{dyna}} = 4.732\%$$

Where k_{dyna} —— dynamic sensitivity of measurement system;

Δk_{dyna} —— standard deviation of dynamic sensitivity of measurement system;

δ_{dyna} —— relative uncertainty of dynamic sensitivity

Table 1 the results of calibration of dynamic sensitivity

P_r calculated by shock tube theory (MP)	0.1905	0.2657	0.2592	0.2465	0.1644	0.2465	0.2528	0.2724	0.2592	0.1575
Output(mV)	961.5	1310.3	1270.4	1195.7	834.5	1200.7	1195.7	1305.3	1280.4	772.2
P_r calculated by shock tube theory (MP)	0.1428	0.2528	0.2457	0.2583	0.2457	0.2396	0.2393	0.2712	0.2457	0.2865
Output(mV)	682.5	1195.7	1180.7	1260.4	1195.7	1195.7	1245.5	1320.2	1220.6	1384.0

3.2. Overshoot Values of System and Uncertainty Analysis after They are Corrected

The result of a dynamic pressure measurement is a time series of pressure values. For transient signal such as air shock wave pressure, it is always necessary to be corrected the measurement values to obtain a better estimation of the true pressure curve. The correction method of dynamic characteristic was presented [7]. Multi-experiments of dynamic response and their correction were carried out. A group of typical results can be seen in Fig.3 and Fig.4. The statistical result of overshoot values of the system to be corrected show in table2. Its uncertainty (confidence level is 95%) is as follows:

$\delta_{over} = \max(\Delta) = 9.4\%$

δ_{over} — Relative uncertainty caused by dynamic characteristic.

Table 3 the statistical results of overshoot and its correction

No. of experiment	Pressure P_r of dwell time (MPa)	Maximum $P_{r\max}$ of response curve (MPa)	Overshoot value $\Delta = \frac{P_{r\max} - P_r}{P_r} \times 100\%$
1	0.1930	0.2076	7.6
2	0.2630	0.2767	5.2
3	0.2550	0.2687	5.4
4	0.2400	0.2687	7.2
5	0.1675	0.1768	5.6
6	0.2410	0.2572	6.7
7	0.2400	0.2550	6.3
8	0.2620	0.2800	6.9
9	0.2570	0.27545	6.8
10	0.1550	0.1670	8.0
11	0.1370	0.1499	9.4
12	0.2400	0.2545	6.1
13	0.2370	0.2501	5.5
14	0.2530	0.2680	5.9
15	0.2400	0.2610	8.75
16	0.2400	0.2523	5.1
17	0.2500	0.2600	4.0
18	0.2650	0.2800	5.7
19	0.2450	0.2594	4.7
20	0.2778	0.2975	7.0

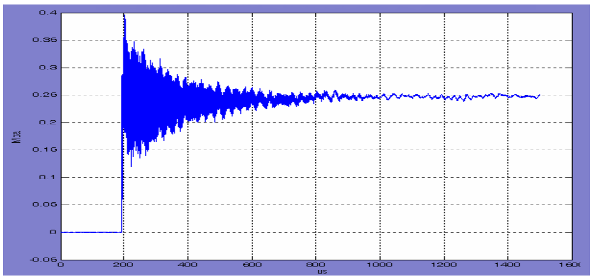

Fig.3 a typical response curve excited by shock tube

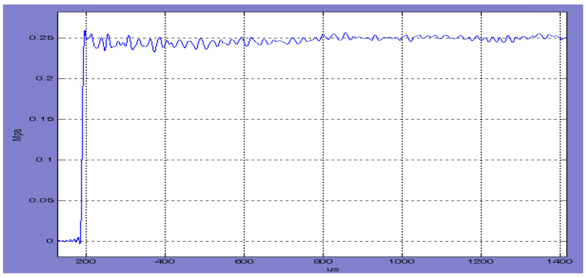

Fig.4 corrected curve of Fig.3

3.3. Effect of Impact Acceleration of the Measurement System

In the environment of measuring air shock wave pressure, measurement systems will endure vibration or shock. So, besides mounting considerations, a factor to influence measurement uncertainty is response to acceleration inputs, whether they are shock, vibration or static acceleration. According to the specification of sensor used, the response is smaller. Its sensitivity is 0.00015 equivalent psi/g. If maximum impact acceleration (confidence level is 95%) is 5000g, then additional output of the system is 0.75psi or 0.75%FSO. So,

$\delta_{acce} = 0.75\%$

δ_{acce} —— Relative uncertainty caused by impact acceleration.

3.4. Photoflash Response of the Measurement System

The sensor' response to a transient flash of intense illumination is another factor to cause uncertainty. According to the specification of sensor, this kind of sensor's response to the specified light source as described in the ISA Standard (ISAS37.10,Para.6.7,Procedure 1) is measured as 0.6 psi, or 0.6%FSO. If supposing this result is relative standard deviation, then relative uncertainty is as follows (confidence level is 95%):

$\delta_{flash} = 2 \times 0.6\% = 1.2\%$

δ_{flash} ——Relative uncertainty caused by flash of intense illumination

3.5. Combining Uncertainty Components of the Measurement System

In terms of the theory of relative combining uncertainty components, the combining uncertainty mentioned above can be calculated as follows:

$$\delta_2 = \sqrt{\delta^2{}_{dyna} + \delta^2{}_{over} + \delta^2{}_{acce} + \delta^2{}_{flash}}$$

$$= \sqrt{(4.732\%)^2 + (9.4\%)^2 + (0.75\%)^2 + (1.2\%)^2} = 10.6\%$$

Fig.5 is an origin curve of measurement system. Fig.6 is its estimation.

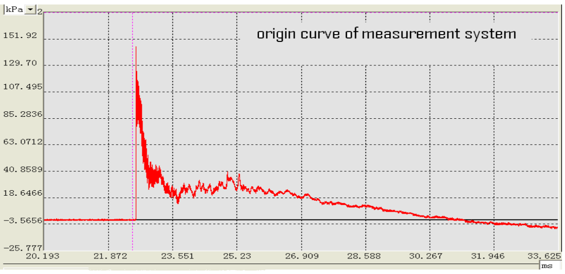

Fig.5 an origin curve of measurement system

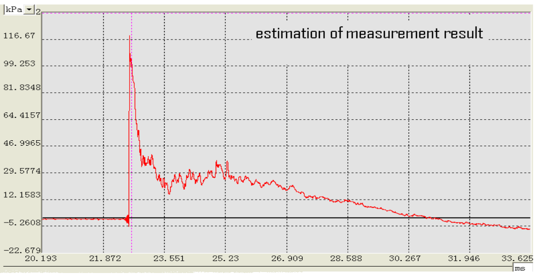

Fig.6 estimation of measurement result Fig.5

4. CONCLUSIONS

The paper gives several main components of uncertainty and their experimental data of the measurement system of air shock wave pressure, especially analyses and processes dynamic sensitivity and overshoot values of the system excited by step pressure signal which is generated by shock tube. The method of dynamic uncertainty provides a kind of solution to analyze and assess the result of single measurement or a few measurements.

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