MICRO EXPLOSION CUSHION ANTI HIGH OVERLOADING DATA ACQUISITION SYSTEM

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Abstract - *In this paper a typical on-board Micro Data Acquisition System used for dynamic data measurement in various rockets and missiles is introduced. It is composed of: MEMS transducers, signal acquisition module, data compression module, memory circuit and necessary control circuit. The application environments have special requirements for the device, among which these two are critical: one is the limitation of the volume and weight, and the other is the anti high overloading ability of the device. The volume and weight are reduced by the use of MEMS technology and real time data coding/compressing. With the help of explosion cushion, the anti high overloading ability of the system is enhanced.*

Keywords - Micro acquisition system; MEMS; Data real-time compression;

1. INTRODUCTION

Micro Data Acquisition System (MDAS) is a kind of Microsystems that integrated the measurement, sampling, quantization, coding/compressing and storing together. It can be used in the dynamic data measurement of rockets, missiles and vehicles. With the development of technology such as MEMS (Micro Electronicmechanical System), Micro Electronics, DSP etc., the application of MDAS will be widened greatly, for example, it can be used in the around-the-clock human body state and ambient environment monitoring with the data recorded by its memory and then output to the hard disk through the interface with the computer, which will be used in the later analysis of human health. In these applications, micromation is the key, the applications are extended each time when the system volume is reduced, sometimes even create a completely new field[1]. MEMS (Micro Electronic Mechanical System) technology, which refers to the technologies and practice of making three dimensional structures and devices with dimensions in the order of micrometers, bring great chance to MDAS. Besides the reduction of volume, there are other advantages such as volume-produce, high integration level, high reliability and so on. Nowadays, there are two main MEMS techniques in use / under development, one is silicon-based technology and the other is LIGA. Silicon-based technology is the best developed MEMS technology since silicon is the primary substrate material used in production of microelectronic circuitry, and so is the most suitable candidate for the eventual production of Microsystems. LIGA is developed in Germany, which is the abbreviation of German “Lithographie, Galvanoformung, Abformung” for lithography, electroplating, and molding. The process can yield extremely high-aspect-ratio metallic structures thanks to the use of extremely well-collimated synchrotron radiation (x-rays) to expose the template layer with nearly perfectly straight sidewalls. The MDAS discussed below is produced by the silicon-based techniques. According to the actual application requirement, two points are considered specially in the design of the system, which are the micromation and the anti high overloading ability[2]-[4].

2. MICROMATION TECHNOLOGY

The MDAS comprises silicon micromachined transducers, an ASIC with self-adaptation collecting and storing control function, RAMs and power controller. The principle demonstration is showed in Fig.1. The measured data are stored in RAMs in real time, which can be outputted to the computer later through the interface with the computer. Through system model building and analysis, one conclusion is made that the transducer and the memory circuit are the main factors that determine the volume of the entire measurement system, especially in conditions where the data size is very large.

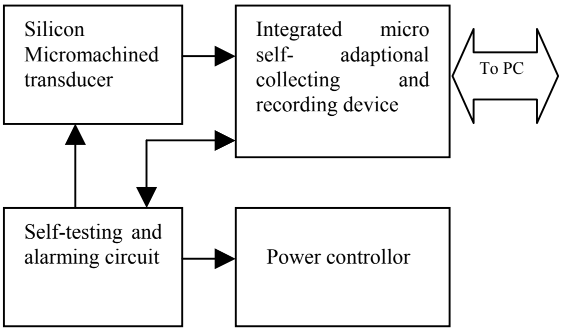

Fig.1– Demonstration of the MDAS’ components

2.1. MICROMATION OF THE TRANSDUCERS

In order to reduce the volume of the system the transducer is designed and fabricated using silicon-based MEMS technology. There are five parameters that need to be measured, which are x-axis acceleration, y-axis acceleration, z-axis acceleration, pressure and temperature, which is used to compensate acceleration temperature drift.

The principal of the accelerometer is piezoresistance. Only one shared proof mass is used to measure the three-dimensional accelerations as is realized by enlarging the axis-crossing error (usually between 0.5%-2% in the typical single–axis piezoresistor accelerometer) to 20%, and real time uncoupling algorithm is produced that can separate the three-dimensional accelerations completely. The structure of the accelerometer is composed of four pairs of cantilever and one center proof mass, sixteen resistance are made on the cantilevers whose resistivity changes reflect the changes of stress caused by the change of the acceleration. Thus, with the aid of on-chip circuit the acceleration of the three direction (x,y,z) can be measured separately at the same time.

The following is the analysis of the x axis acceleration measurement. The seperation of y and z axis acceleration is similar.

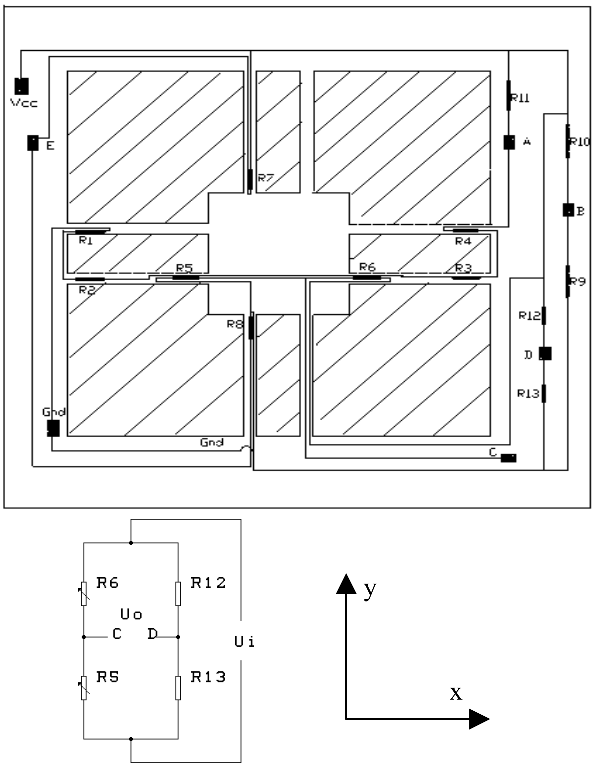

Fig.2. Piezoresistor/metal line collocation on the chip (above) and separating bridge (below)

The output of x axis (see Fig.2) accelerometer is as below,

$$U_{ox}=U_C-U_D$$

$$=\frac{R_5+\Delta R_{5xi}+\Delta R_{5xm}+\Delta R_{5yi}+\Delta R_{5ym}+\Delta R_{5z}}{(R_5+\Delta R_{5xi}+\Delta R_{5xm}+\Delta R_{5yi}+\Delta R_{5ym}+\Delta R_{5z}+R_6+\Delta R_{6xi}+\Delta R_{6xm}+\Delta R_{6yi}+\Delta R_{6ym}+\Delta R_{6z})}U_i-\frac{1}{2}U_i$$

where, U_{ox} is the output voltage,

ΔR_{jxi} ($\Delta Rjyi$) is the resistance change of the jth resistor caused by the x (y) inertia force,

$\Delta Rjxm$ ($\Delta Rjym$) is the the resistance change of the jth resistor caused by the x (y) inertia moment,

ΔRjz is the is the resistance change of the jth resistor caused by the z inertia force,

$\Delta R_{5xi}=R\pi\sigma_{4xi}$, $\Delta R_{5xm}=R\pi\sigma_{4xm}$, $\Delta R_{5yi}=R\pi\sigma_{4yi}$,

$\Delta R_{5ym}=R\pi\sigma_{4ym}$, $\Delta R_{5z}=R\pi\sigma_{4z}$, $\Delta R_{6xi}=R\pi\sigma_{14xi}$,

$\Delta R_{6xm}=R\pi\sigma_{14xm}$, $\Delta R_{6yi}=R\pi\sigma_{14yi}$,

$\Delta R_{6ym}=R\pi\sigma_{14ym}$, $\Delta R_{6z}=R\pi\sigma_{14z}$

From the mechanical calculation (not listed in this paper), we know that:

$\sigma_{4xi}=-\sigma_{14xi}$, $\sigma_{4xm}=-\sigma_{14xm}$, $\sigma_{4yi}=\sigma_{14yi}$, $\sigma_{4ym}=\sigma_{14ym}$, $\sigma_{4z}=\sigma_{14z}$,

So, the above formula can be simplified as below,

$$U_{ox}=\frac{\Delta R_{5xi}+\Delta R_{5xm}}{2(R+\Delta R_{5yi}+\Delta R_{5ym}+\Delta R_{5z})}U_i$$

$$\approx\frac{\Delta R_{5xi}+\Delta R_{5xm}}{2R}U_i$$

$$=\frac{1}{2}(\pi\sigma_{4xi}+\pi\sigma_{4xm})U_i$$

and the sensitivity of x axis acceleration is:

$$S_x=\frac{1}{2}\frac{\pi\sigma_{4xi}+\pi\sigma_{4xm}}{a_x}$$

from which we can see that theoretically x acceleration can be separated from y and z axis acceleration completely in this way.

Ansys software is used to analyze the displacement, yield character and resonance frequency. The total structure is modeled although it is two-dimensional symmetry because the force might be nonsymmetry. Figure 3 is the finite-element distortion under press and Figure 4 shows the displacement along the beam. The solid 45 3D element is used, all the elements are standard cuboids, the ratio between length, width and height is near 1:1:1. The total number of the elements is 8868 corresponding to 10080 nodes. The characteristic of the material used in the calculations are as follows: Young's Modulus=130×10^9Pa, Shear Modulus=79×10^9Pa, density=2.33×10^3Kg/m^3, poisson ratio=0.18. Analysis show that 3000g is the maximal acceleration with this structure of which the displacement meet the requirement of the linearity, the maximal stress, which happen in the connect place (somewhat near the support frame) , is under yield stress, and the resonance frequency (71.4kHz by calculation) is far from the work frequency, which is about 2-2kHz

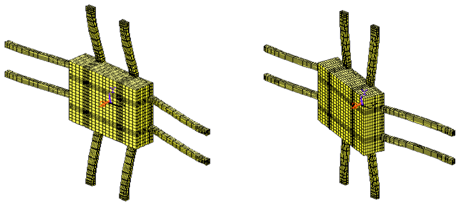

Fig.3. The finite-element distortion under inertial force

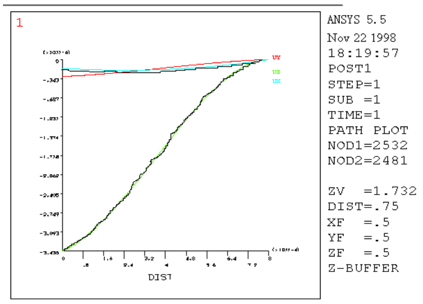

Fig.4. The displacement along the beam

The basic process used to fabricate the accelerometers began with (100) double polished silicon wafer, oxide is growth and patterned to act as mask, two diffusions are then carried out, one for 2Ω/square n+ connect wire and one for 400Ω/square n+ piezoresistors. At this point annealing is required to eliminate disfigurement. The movement space of the proof mass is then etched with similar method, followed by the RIE etching of the beams. After that TiPtAu wire is evaporated by sputtering. Finally, the proof mass is released by EPW anisotropic wet etchant with SiO_2 mask. The SEM photograph of the three-dimensional accelerometer is shown in figure5.

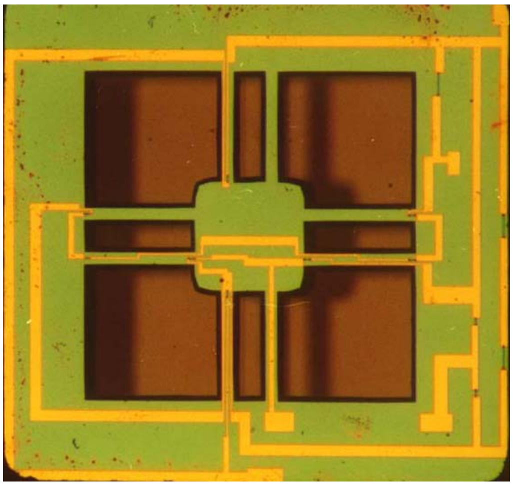

Fig.5. The SEM photograph of the three-dimensional accelerometer

To measure the pressure of the environment and to compensate the temperature drift, a pressure/temperature senser is designed and integrated with three-dimensional accelerometer by micro assemble technique. The pressure/temperature sensing unit need totally 6 masks, three of which are used for the fabrication of movable plates and three of which are used for the fabrication of temperature-sensible diode. The movable plate is released by heavy-doped boron self-stopped anisotropic etch. The space between the two capacitances plates is controlled by RIE etching and the place corresponding to the wire on the glass dice is also etched with the same mask to ensure the reliability of the latter bonding. The unmovable plate, reference plate and metal wires are deposited on the glass wafers by evaporation. Finally, the silicon wafer and the glass wafer are bonded together by anode-bonding process. Two hermetic modes are used, one is epoxy seal and the other is self-grown seal.

2.2 REAL TIME DATA COMPRESSION TECHNOLOGY

The other way to reduce the volume of the device is to use real time data compression technology. A novel real time data compression algorithm is produced, which is based on the maxim relative error. We have accomplished ASIC that compress the collecting data in real time, with the compressive ratio up to 127:1. Fig.6. and Fig7 are respectively the timing sequence diagram and the photograph of the ASIC. The compressive algorithmic used on the chip is showed below,

Assumed equal-step sampling is used, one gets sample sequence $\{x_k\}$.

Domain, $U=(x_k) \subset R$, Range, $V=(x_{ni},m_k) \subset R \times N$, $n_{k+1}=n_l+m_k$

U,V are ordered set (sequence).

Definition operator, *T*, $U \rightarrow V$, and, $T = T_2 T_1$

Where,

$$T_1 x_k = \begin{cases} (x_1, 0), k=1 \\ \Gamma(T_1 x_{k-1}, (x_k, 0)), k \geq 2 \end{cases},$$

$$x_k \in R, k \in N$$

$$\Gamma((x,k),(y,0)) = \begin{cases} (x,k+1), |y-x| \leq E \\ (y,0), |y-x| \rangle E \end{cases},$$

$$x, y \in R, k \in N$$

E is the given tolerance.

$$T_2(x_i,k_i) = \begin{cases} (x_i,k_i), x_i \neq x_{i+1} \\ T_2(x_{i+1},k_{i+1}), x_i = x_{i+1} \end{cases},$$

$$x_i \in R, k_i \in N$$

Then, ***T*** is the data-compressive algorithmic.

With the operator ***T*** known, set *U* is completely defined by set V. So all the measured information can be memorized by storaging set V, which means save of large memory space.

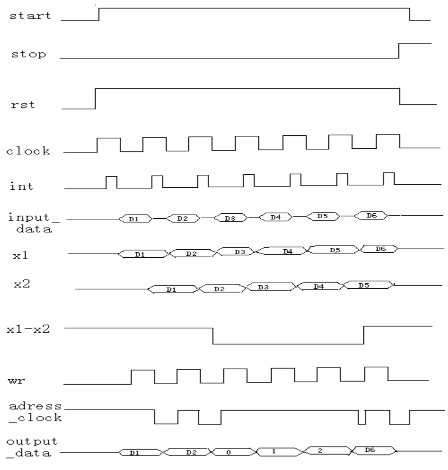

Fig.6.The timing sequence diagram of the compressing ASIC

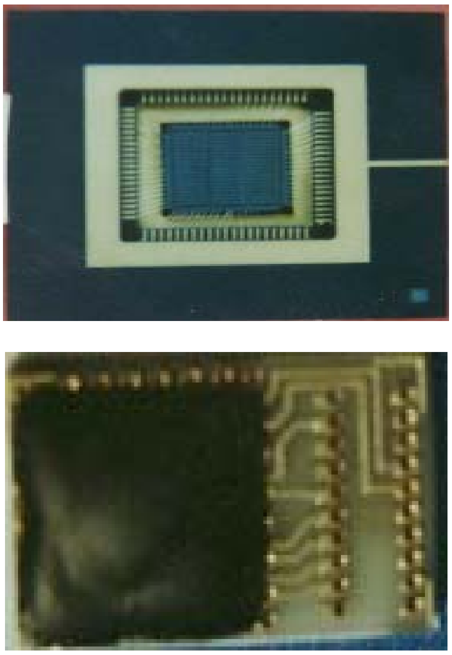

Fig.7. The photograph of the ASIC

3.EXPLOSION CUSHION ANTI HIGH OVERLOADING TECHNOLOGY

The maxim overload in the real application may exceed 200,000g. At the same time, the space, shape, and weight of the data acquisition devices are all fixed so that no material available can sustain the overloading. Buffering technology must be used, but the conventional method is almost invalid because of the high overload. We designed a special buffering technology named “explosion cushion technology”, which makes use of the high-pressure gas formed during the blasting moment to buffer the high overload. The key points of the technology include control of the fuse and blasting pressure variation curve, the latter is the critical to realize the expected buffer effect. A special explosive charges and integration method with the data acquisition system are researched; the experiment curve of the blasting pressure is obtained, based on which calculation shows that the technology can enhance the anti-overloading ability of the device threefold.

4. CONCLUSIONS

Micro Data Acquisition System application is very abroad, the micromation technology of the MDAS can extended its application field to some special environment. The use of mulit-parameter transducer based on MEMS technology can reduce the volume and weight of the system greatly and enhance the reliability at the same time. For some special application, the real-time coding/compressing ASIC is needed, the maxim relative error algorithmic produced in this paper is proved to be an effective method. Although not usually met, high overload is a problem limiting the application of the MDAS in some environments, explosion cushion anti high overloading technology is a way to reduce the overloading with great prospect.

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REFERENCES

[1] Wendong Zhang, HaifengDong, “New Medical Treatment and Health Protection Conception Based on the MEMS technology”, *The 2001 conference of Chinese Science Society.*

[2] Gregory T.A. Kovacs, “Micromachined Transducer Sourcebook,” WCB McGraw-Hill, 1998

[3] Hiroyuki Fujita “Future of actuators and Microsystems” *Sensors and Actuators A56(1996)105-11*

[4] Hidekuni Takao, Yoshinori Matsumoto etc. “Three dimensional vector accelerometer using SOI structure for high temperature” *TRANDUCERS ’95 EUROSENSORS IX 409-PC12*

[5] Chr.Burrer, J.Esteve etc. “Fabrication and characterization of a twin-mass accelerometer” Sensor and Actuatators A,43 (1994) 115-119

[6] Wendong Zhang “The Application of an Inegrated Micro Self-adaptive Sampling Measurement System in Transportation” *1997 World Micromachine Summit Session 6*

[7] Guangyu Liu Ming Chen “New Type Sensor Technology and Application” *Beijing Aerospace and Aviation Publish House 1995*

[8] M.Offenberg, F.Larmer etc. “Novel process for a monolithic integrated accelerometer” *The 8th International Conference on Solid State Sensors and Actuators and Eurosensors IX Stockholm, Sweden.June 25-29,1995*

[9] Wendong Zhang et al. The Intelligent Missile Black-box, *IEEE Transaction on Instrument and Measurement June, 1995.*