

# Digital signal processing methods of hammer vibration energy analysis based on FPGA

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## Abstract

The hammer of 630KJ is an advanced forge device, whose hit energy and hit power during forge process are the key elements to forge quality. Therefore, from analyzing mathematical model of hit power, the forge quality can be developed. In this paper, the device we designed can measure acceleration change during forge, from which the mathematical model between acceleration and hit power can be constructed according to the change discipline between them. The digital signal processing system of functional model based on FPGA is designed, in which Verilog HDL program language compiled by Quartus II environment is downloaded into FPGA to implement all the functions. Such method can improve the speed of digital signal processing, from which the max hit power and the max hit energy can be got according to acceleration and displacement.

*Keywords:* vibration energy, verilog HDL, digital signal processing

## 1 Introduction

With the development of aviation forging industry, the hammer position becomes very important in the aviation forging industry. In the progress of hammer forging, hit energy is the key parameter to control the accuracy of forging. The parameter measurement is a necessary condition for forging process quality control and the normal operation of equipment. According to the layout of large number of instruments and equipment, it can't meet the test requirements of continuous production process in the field of measuring and testing methods in the tradition.

In order to grasp the function performance and quantize the attack process of the device in different stages, the establishment of various stages of energy formula and different stages of the energy relation is explored based on the hammer acceleration, displacement analysis. To establish the mathematical model of the equipment against energy, knowledge of digital signal processing method is used. Verilog HDL program language compiled by Quartus II environment is downloaded into FPGA to design a set of power digital signal processing hardware circuit system model transformation [1].

## 2 System design principle

The working media in the ideal design principle of forging hammer is steam, whose theoretical work pressure is 0.8Mpa. However, compressed-air is the real working media during actual work and the actual work pressure can only reach 0.65Mpa. The hammer working principle is to replace the hammer anvil fixed activity. Connecting mechanism, the under hammer strikes the upper one, which makes the forge object deformation [2].

The whole system working principle diagram is shown as follows:

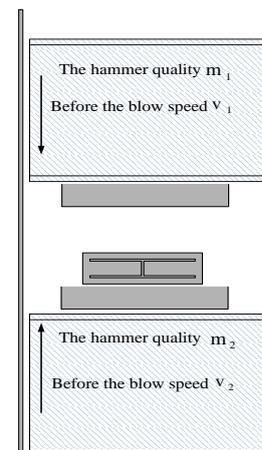


FIGURE 1 System working principle diagram

Standard specification is hit energy label. The hit is equal to the sum kinetic energy of under and the upper hammer, in which the value of the two energies are the same. The energy ratio between upper and under hammer is shown as follows:

$$\frac{V_2}{V_1} = \frac{m_1}{m_2} = \frac{H_1}{H_2} \quad (1)$$

The under and the upper hammer hit each other controlled by linkage rod, whose moving discipline is the same. The hammer to strike the hit energy in the moment is shown as follows:

$$E_h = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 \quad (2)$$

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$E_h$  – Instant hit energy;  
 $m_1$  – Quality of upper hammer head;  
 $m_2$  – Quality of under hammer head;  
 $v_1$  – Upper hammer hit instantaneous velocity;  
 $v_2$  – Under hammer hit instantaneous velocity.

**3 Energy parameters analysis**

**3.1 MATHEMATICAL MODEL ANALYSIS**

The momentary move value of under hammer and upper hammer is the same in this analysis of the system. In the fight against the moment, under the hammer hit speed quickly into the rebound velocity, of which the recovery coefficient is calculated as follows:

$$K = \frac{V_2 - V_1}{V_1' - V_2'} \tag{3}$$

$$v_1' = -Kv_1, \tag{4}$$

$$v_2' = -Kv_2, \tag{5}$$

$$V_2 = \int_0^{t_2} a' dt = \frac{1}{2} a' t_2^2. \tag{6}$$

Inertia force and the moving parts is forging stress analysis and strength check for main parts. The same energy of the hammer hit force is decided by size, shape and forging temperature of hammer. The hit power is different in each hitting process based on the same hammer [3]. Forging deformation energy is calculated as follows:

$$E_d = \frac{1}{2} (1 - K^2) (m_1 v_1^2 + m_2 v_2^2), \tag{7}$$

$$\eta = \frac{E_d}{E_h} = 1 - K^2. \tag{8}$$

**3.2 MAXIMUM HITTING FORCE ANALYSIS**

In the fight against the moment, under the hammer hit speed quickly into the rebound velocity, which the recovery coefficient is calculated as follows:

$$K = \frac{V_2 - V_1}{V_1' - V_2'} \tag{9}$$

In the collision process, each hit has a very short time, which can be used to analyze energy change before and after the attack the momentum conservation law in physics and theorem of impulse. The hammer hit process is divided into two stages. The first stage is the loading stage, under the hammer hit forging relative, the elastic and plastic deformation. The deformation happens. And then hammer move at the same speed towards the small direction. The second stage is the unloading stage. In the first stage the upper and under head apart in opposite directions at

different speeds, as the elastic energy of the mould and forging object release. The conservation of momentum is shown as follows:

$$m_1 V_1 + m_2 V_2 = m_1 V_1' + m_2 V_2' = (m_1 + m_2) V_C, \tag{10}$$

$V_C$  is the under hammer hit system on the gravity in the process speed:

$$P \Delta t = m_2 V_2 - m_2 V_C = -(m_1 V_1 - m_1 V_C), \tag{11}$$

$P$  – force

$\Delta t$  – Stroke time

The force calculation equation is shown as follows:

$$P = \frac{m_2 V_{2o} - m_2 V_C}{\Delta t} = - \frac{m_1 V_{1o} - m_1 V_C}{\Delta t}, \tag{12}$$

$$V_C = \frac{m_1 V_{1o} + m_2 V_{2o}}{m_1 + m_2}. \tag{13}$$

Attack time of hammer started forging time (the maximum time attack speed) period of time to complete the hammer hit bounce time (the maximum time hopping speed).

**3.3 MAXIMUM HITTING ENERGY ANALYSIS**

The hammer hit against the total energy accumulation in the moment is calculated as follows:

$$E_h = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2, \tag{14}$$

Strike instantly after the hammer rebound velocity is calculated as follows:

$$V_1' = V_1 - \frac{m_2}{m_1 + m_2} (V_1 - V_2) (1 + K), \tag{15}$$

Under the hammer rebound velocity is calculated as follows:

$$V_2' = V_2 + \frac{m_2}{m_1 + m_2} (V_1 - V_2) (1 + K). \tag{16}$$

Two hammer residual energy of hammer is calculated as follows:

$$E_s = \frac{(m_1 V_1 + m_2 V_2)^2 + K^2 m_1 m_2 (V_1 - V_2)^2}{2(m_1 + m_2)}, \tag{17}$$

Forging the absorbed energy is calculated as follows:

$$E_d = E_h - E_s = \frac{m_1 m_2 (V_2 - V_2')^2 (1 - K^2)}{2(m_1 + m_2)}. \tag{18}$$

3.4 ACCELERATION CALCULATION ANALYSIS

The acceleration change process of hammer hit as shown as follows:

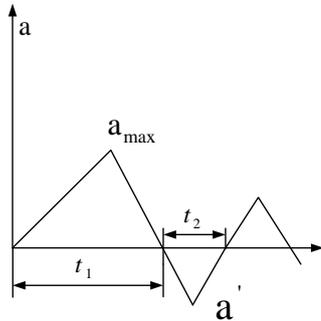


FIGURE 2 The acceleration diagram

$t_1$  is the time for the hammer hit accelerated movement before hitting forging object;  $t_2$  is the time for hammer hit billet deformation time.

Under the hammer hit instantaneous speed is calculated as follows:

$$V_2 = \int_0^{t_1} a_{max} dt = \frac{1}{2} a_{max} t_1, \tag{19}$$

Under the hammer hit after spring-back speed is calculated as follows:

$$V_2' = \int_0^{t_2} a' dt = \frac{1}{2} a' t_2, \tag{20}$$

If set  $m_1 = m$ ,  $m_2 = \lambda m$ ,  $V_1 = V$ ,  $V_2 = -V$ ,

$$V_1' = V - \lambda V - \lambda V_2', \tag{21}$$

Recovery coefficient is calculated as follows:

$$\varepsilon = \frac{V_2' - V_1'}{2V} = \frac{V_2' - V + \lambda V + \lambda V_2'}{2V}, \tag{22}$$

$$E_h = \frac{1}{2} m V^2 (1 + \lambda), \tag{23}$$

$$E_s = \frac{(1 - \lambda)^2 + 4\alpha\varepsilon^2}{2(1 + \lambda)} m V^2. \tag{24}$$

Hit energy (forgings absorption of energy) is calculated as follows:

$$E_d = E_h - E_s = \frac{2\lambda(1 - \varepsilon^2)}{1 + \lambda} m V^2. \tag{25}$$

Force time is calculated as follows:

$$\Delta t = t_2. \tag{26}$$

Force is calculated as follows:

$$P = \frac{2\lambda m V}{t_2(1 + \lambda)}. \tag{27}$$

4 Software design

4.1 TOP-LEVEL MODULE DESIGN

Since acceleration is a key factor to combat force, how to collect the acceleration signal relatively accurate becomes very important. Because the vibration in the actual working environment is very big, data collected by sensors are often accompanied with 50Hz frequency interference. Therefore, high-peaker on the two accelerations is accepted [4]. The top-level module block diagram is shown as follows:

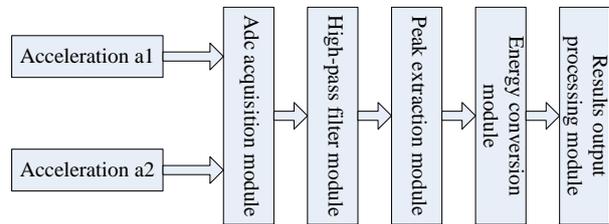


FIGURE 3 The top-level module diagram

In MELP algorithm in the pre-processing part, the main filter 50Hz frequency interference should be removed, in which 4 order Chebyshev high pass filter is used. A signal of truncated frequency under 60Hz is removed. The stop-band attenuation is 30db.

Because the attack time is in milliseconds, the acquisition time of the system for data about 500ms before and after the hit process. The maximum acceleration signals are needed to extract. Therefore a peak extraction module should be designed, in which this time data were compared to extract the maximum acceleration peak value of the two signals. After the establishment of extraction, mathematical model using Verilog HDL language is established [5]. The maximum acceleration peak value is calculated as follows:

$$E_s = \frac{(1 - \lambda)^2 + 4\alpha\varepsilon^2}{4(1 + \lambda)} m a_{max}^2 t_1^2, \tag{28}$$

Final output maximum force is calculated as follows:

$$P = \frac{2\lambda m V}{t_2(1 + \lambda)}. \tag{29}$$

The biggest hit energy (forgings absorption of energy) is calculated as follows:

$$E_d = E_h - E_s = \frac{\lambda(1 - \varepsilon^2)}{2(1 + \lambda)} m a_{max}^2 t_1^2. \tag{30}$$

4.2 SINGLE MODULE DESIGN

The relationship of conversion and max-value between hit and force parameter on the moment during forging process is studied in this system. First of all, AD1[11:0] and AD2[11:0] data is collected by the device and handled by high pass filter. In order to remove frequency interference filter system of 50Hz, 4 order DC filter is used [6].The high-pass filtering module diagram is shown as fellow. Please see Figure 4.

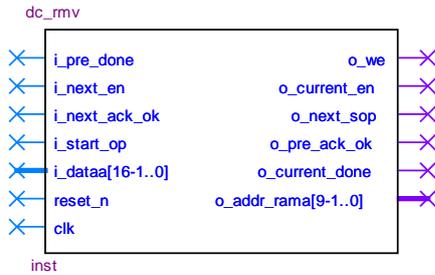


FIGURE 4 The high-pass filtering module diagram

Two data after filter of dc\_in1[11:0], dc\_in2 the [11:0] are sent into the peak extraction module. Due to hit time is very short, the acceleration signal in 500ms are compared and output, which is shown as follows [7]:

TABLE 1 Peak comparison module input and output value of the mapping

Top_compare input	cha_data_in	cha_data_in	Counter
Top_compare output	cha_data_out	cha_data_out	16

The top of the module which set up in QuartusII is shown as follows:

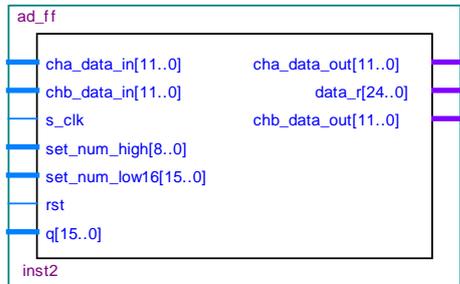


FIGURE 5 The top level module diagram

System clock frequency is 50 MHz. The output frequency of clk\_div is 1KHz. The counter module is established. And the minimum and maximum values of the acceleration can be got in the 500ms.

References

[1] Jin W, Ma W, Yang S 2008 The Simulation Research on Blowing Energy of 50kJ Hydraulic Die Forging Hammer *China Metal Forming Equipment & Manufacturing Technology* 43(5) 90-2 (in Chinese)  
 [2] Jin W, Yang S, Zhang T 1999 Research on Energy Parameters of 50 kJ Hydraulic Forging Hammer *China Mechanical Engineering* 10(6) 605-6 (in Chinese)

5 Simulation and test result

The mathematical model of the hammer hit energy is established, which has been proved by simulation in QuartusII environment. The simulation is set in an ideal environment and the initial pressure is in the 0.65MPa. The test result is consistent with the simulation process. After the actual several times test, the hit force and energy test data is calculated:

TABLE 2 Hit force and energy test result

Hit number	1	2	3	4	5
Hit force(MN)	259.6	123.5	398.7	564.2	789.1
Hit energy(kJ)	119.7	436.9	282.5	367.6	90.8
Hit speed(m/s)	2.9507	1.9507	1.8793	2.0493	2.5565
Initial pressure(Mpa)	0.61	0.65	0.67	0.68	0.66

The relationship between acceleration and force energy is simulated in different die height and the fight against stroke.

6 Conclusion

In this paper, through qualitative and quantitative analysis of various factors hammer hit energy, the mathematical model simulation model Verilog HDL language platform is established. Relationship between the acceleration parameter and the impact energy was simulated, and the hit stroke and acceleration are key factors influencing the combat performance.

The actual measurement shows that the mathematical model in this design, compared with the actual measurement results of this system, is reliable, which can provide a theoretical basis for control hit energy.

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[3] Roundy S 2003 A study of low level vibrations as a power source for wireless sensor nodes *Computer Communications* 26(11) 1131-44  
 [4] Kuehne I, Frey A, Eckstein G 2006 Design and Analysis of a Capacitive Vibration-To-Electrical Energy Converter with Built-In Voltage *Solid-State Device Research Conference* 138-41  
 [5] Liu J, Yang D, Wen H, Liu C 2013 FPGA high-speed data acquisition system based on USB communication *Modern Electronics Technique* 34(10) 186-92

[6] Gao Y, Hou Z 2007 Based on FPGA and USB high speed data acquisition and transmission system *Industry and Mine Automation* 4(8) 105-6

[7] Mayer-Lindenberg F 2009 High-level FPGA Programming through Mapping Process Networks to FPGA Resources *IEEE International Conference on Reconfigurable Computing and FPGAs* 1-6

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