

Research on dynamic modelling methods of Gatling gun

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Abstract: According to the characteristics of loop shooting for the Gatling gun, the measured or calculated barrel pressure data are taken in simulation. The functions and sensors in ADAMS are used comprehensively. The barrel force and other forces are added in simulation. Some relative dynamic parameters of the Gatling gun are attained. The results obtained in simulation are compared with the real test to verify the accuracy of the simulation.

1. Introduction

The artillery is a complex electro-mechanical-hydraulic integrated product which structure and launch principle are complex. The traditional artillery design theory mainly discusses the static design theory based on the assumption of stillness. It is difficult to describe the Physical characteristics of the Gatling gun accurately. And the design-manufacture-test is an iterative process resulting in its long development period and high cost ^[1]. The development of Virtual prototyping technology is important to the research of the Gatling gun. Therefore the Virtual prototyping technology will replace the test partly.

The dynamic research of Gatling guns mostly focused on the guns using external energy presently. The internal Gatling guns using parts of the gunpowder gas drive the tube to rotate and achieve continuous shooting. Therefore the Multi-body dynamics research of the internal Gatling guns is important. The Multi-body dynamics simulation can provide technical support for the research of Shooting frequency and shooting accuracy.

2. Modelling and Loading

2.1. Modeling

The simulation model is complex. The model is created in the CAD software and imported into the ADAMS software. The CAD model should be correct to ensure the accuracy of the simulation. And the CAD model can be directly read in the simulation.

The operation of ADAMS is based on the marker point, such as the rotary deputy, measurement, etc. For example the model can be moved to the desired location using the marker created by the model edge points.

The model should be verified after adding the relational constraint, force and motion. The over-constrained problem should be noticed especially. The related constraint should be replaced by the basic pair if the problem appeared.

2.2. Adding the buffer force during shooting

The automatic shooting mechanism of the Gatling gun has short displacement and big recoil force. The ring spring is taken to buffer in the automatic shooting mechanism. The ADAMS has the rotation spring-damper constraint. However the ring spring cannot be used in the simulation because the ring



spring has different loading stiffness and unloading stiffness. The ring spring can be instead of the single-component. The ring spring test data is used to fit the stiffness curve.

the recoil force can be expressed as the equation(1) shows:

$$F = m\ddot{x} = F(t) - k \cdot x - c \cdot \dot{x} - \mu \cdot m \cdot g \quad (1)$$

In equation(1): where $F(t)$ is the internal force of the barrel, m is the quality of the recoil part, k is load stiffness coefficient of the spring, c is damping coefficient of the spring, μ is the friction Coefficient,

2.3. Adding the internal force of the barrel

2.3.1. Calculating the internal barrel force. The internal barrel force can be divided into the start-up period force of shooting, the bullet movement period force in barrel and the gunpowder gas acting period force according to the classic interior ballistic. The internal barrel force of the start-up period can generally be instead of the gunpowder gas force acting on the bottom of the barrel. The force of bullet movement period and the period of gunpowder gas acting on the front of barrel can be expressed as the equation[2] shows:

$$F_{pt} = \begin{cases} \left(1 + \frac{\omega}{2m}\right) / \left(\varphi_1 + \frac{\omega}{3m}\right) * Ap & (0 \leq t \leq t_g) \\ \left(\varphi_1 + \frac{\omega}{2m}\right) / \left(\varphi_1 + \frac{\omega}{3m}\right) * Ap_g & (t = t_g) \\ \left(\varphi_1 + \frac{\omega}{2m}\right) / \left(\varphi_1 + \frac{\omega}{3m}\right) * Ap_g * e^{-\frac{t}{b}} & (t_g < t \leq t_k) \\ 0 & (t > t_k) \end{cases} \quad (2)$$

In equation(2), where m is the mass of the bullet, ω is the mass of gunpowder, φ_1 is the secondary work coefficient considering the rotation and friction of the bullet, A is the cross-sectional area of barrel, p is the average pressure in the barrel, p_g is the barrel average pressure when bullet lefts the muzzle, b is the time constant to reflect the decay rate of the force in the barrel, t is the beginning time when projectile lefts the muzzle.

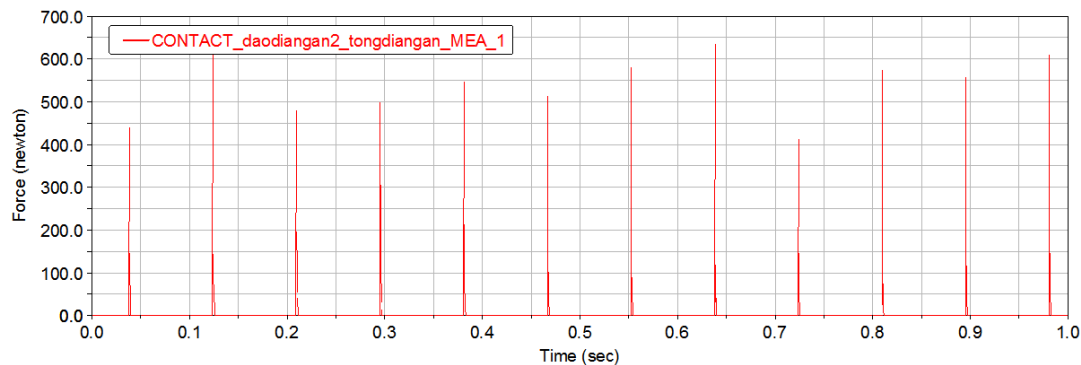
2.3.2. Internal force curve processing. The p - t curve can be attained by the theoretical equation[2]. The theoretical equation should be programmed in MATLAB to calculate the value of the barrel force^[3,4]. The AKISPL function can be used to invoke the barrel force data curve repeatedly in ADAMS^[5].

2.3.3. The problem of the p - t force during simulation. The p - t curve created by MATLAB starts at zero time. However the moment that ADAMS invokes the AKISPL function is not at zero time. Therefore the time should be confirmed by the ADAMS if the AKISPL function is invoked. The sensor is used to solve the problem in ADAMS. The breechblock contacts with the power device when the Gatling gun turns to the fixed position. The Gatling gun starts to shoot after the contact. The contact force of breechblock is used as the shooting factor in simulation. The current time value is returned by the sensor at the same time.

2.3.4. Set up the sensor. The sensor Using the touching time as the shooting factor can be expressed as the following function shows:

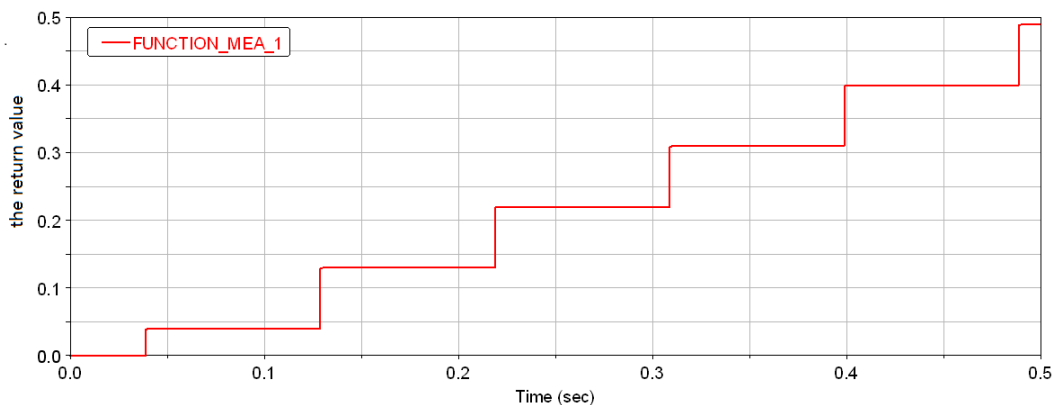
`.MODEL_1.CONTACT_daodiangan_tongdiangan_MEA.`

The contact force between the power device and breechblock shows as the picture1 shows:



Picture1. the contact force between breechblock and power device.

The return value of the sensor shows as the picture 2 shows:



Picture2. the return value of the sensor.

2.3.5. *The function expression of the barrel force.* The function expression of the barrel force as the following function shows:

```
IF(0.5*sign(1,SENVAL(SENSOR_shooting)-0.0001):0,0,
IF( time-SENVAL(SENSOR_shooting): 0,0,
IF( time-SENVAL(SENSOR_shooting)-time_interior_ballistic :
AKISPL(( time-SENVAL(SENSOR_shooting)),0, SPLINE_paotangforce, 0 )
, 0 , 0 )))
```

In the function expression, where the *SENVAL(SENSOR_shooting)* is the return value of the sensor, the *SPLINE_paotangforce* is the curve of the barrel force, the *time_interior ballistic* is the effecting time of interior ballistic.

2.3.6. *The other expression of the barrel force.* The barrel force can also be expressed by the location of gun breech in simulation. The sensor using the location of gun breech as shooting factor can be expressed as: *MODEL_1.MEA_gunbreech_angle*.

The function can be expressed as the following function shows:

```
IF(0.5*sign(1,SENVAL(SENSOR_shooting)-0.0001):0,0,
IF( time-SENVAL(SENSOR_shooting): 0,0,
IF( time-SENVAL(SENSOR_shooting)-0.029 :
AKISPL(( time-SENVAL(SENSOR_shooting)) ,0 , SPLINE_paotangforce, 0 )
, 0 , 0 )
)
)
```

The first form is used to add barrel force in simulation.

2.4. The internal driving force

The internal Gatling gun is pushed by the reciprocating motion of the piston. The gunpowder gas is used to drive the reciprocating piston after shooting. The internal driving force is used to drive the Gatling gun in simulation. The internal driving force is the same as the piston force. The piston force can be calculated by the gas dynamics and thermodynamics theories. And the internal driving force curve can also be expressed and invoked by the AKISPL function in ADAMS. The specific function is expressed as the following shows:

```
IF(0.5*sign(1,SENVAL(SENSOR_shooting)-0.0001):0,0,
IF( time-SENVAL(SENSOR_shooting)-time_cyliner: 0,0,
IF( time-SENVAL(SENSOR_shooting)- time_cyliner -time_piston :
AKISPL((time-SENVAL(SENSOR_shooting)-time_cyliner)
,0 ,SPLINE_houqishi,0) ,0 ,0)))
```

In the function, the *time_cyliner* starts at the beginning of interior ballistic and ends at the time. The time of gunpowder gas effecting the piston can be expressed as the *time_piston*.

2.5. The starting torque

The internal Gatling gun is motioned by the gunpowder gas during shooting. However it should be motioned by the external force firstly at the beginning of the Gatling gun. The external force should be attained by compressing the air. The effecting time of the external force is extremely short and has small effects on shooting. The constant torque is taken as the starting torque in order to simplify the calculation. The starting torque can be expressed as the step function for the purpose of avoiding the sudden change of the force:

```
step( time ,0,0,0.005, step(time,0.005,starting_force,0.05, Step(time,0.05, force0,0.06,0)))
```

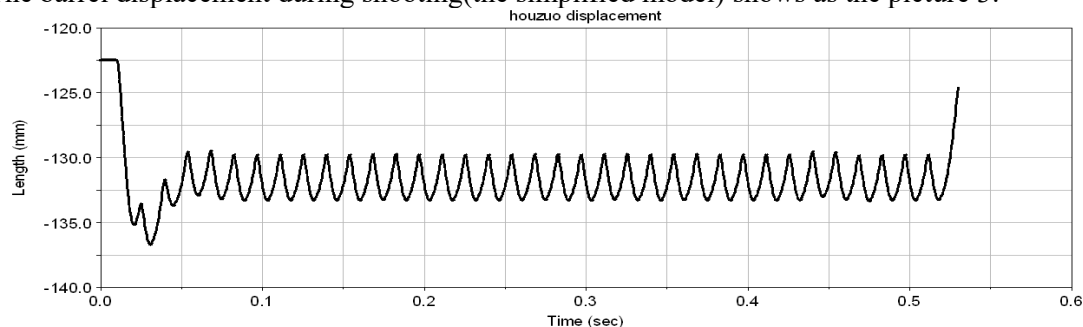
2.6. The resistance torque of the bullet

The resistance torque of the bullet must be considered in the dynamic simulation model due to the influence of internal gunpowder gas. In order to simplify the calculation, the simulation can be instead of the damping force: $a \cdot (\text{MODEL_1.BODAN_v})$ in the equation. Where a is the damping coefficient.

3. Results

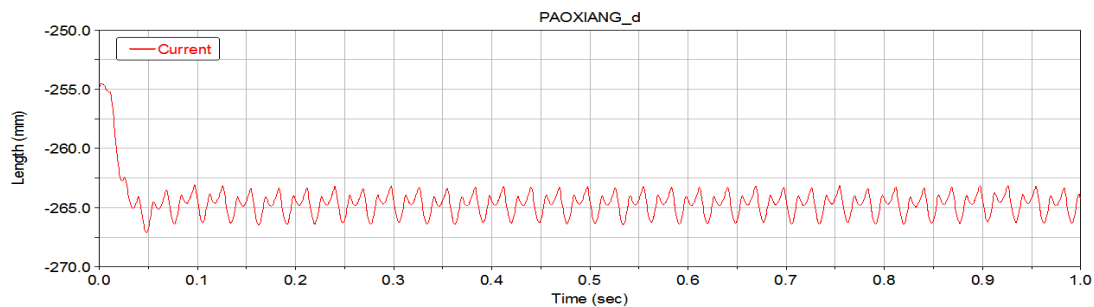
According to the above researches, the internal force of the barrel, the internal driving force, the starting torque, the resistance torque of the bullet is applied in the ADAMS successively. And some important results are obtained in the simulation.

The barrel displacement during shooting(the simplified model) shows as the picture 3:



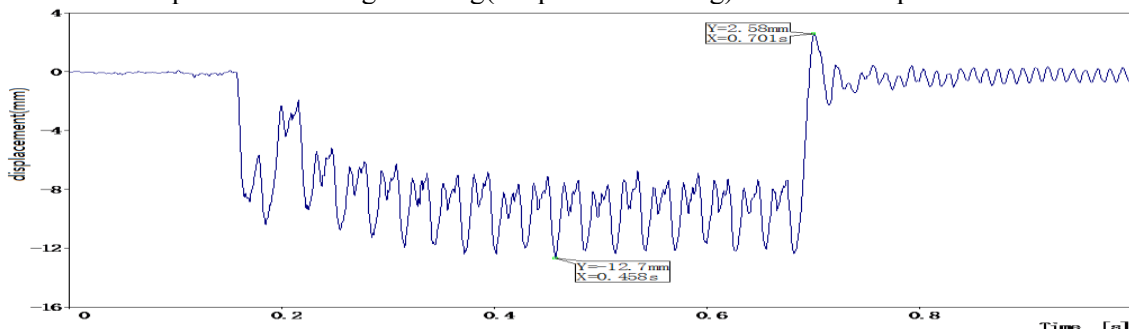
Picture3.the barrel displacement during shooting
(the simplified model).

The barrel displacement during shooting shows as the picture 4:



Picture4.the barrel displacement during shooting.

The barrel displacement during shooting(the practical testing) shows as the picture 5:



Picture5. the barrel displacement during shooting (the practical testing).

4. Conclusion

The application of the Gatling gun barrel force added in the ADAMS is achieved in the simulation. The AKISPL function, if function, sign function and step function is comprehensively used to express the relative force or torque. The simulation results show that the barrel combined force can reflect its dynamic characteristics. And the simulation results are close to the real testing. The methods of loading of the Gatling guns is provided in this simulation and it lays the foundation of the dynamic simulation under different shooting conditions.

References

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