# Parameter identification of inherent characteristics of inertial stability platform

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**Abstract:** Rotary inertia, damping coefficient and stiffness are closely related to the inherent characteristics of rotary inertial stability platform(ISP). The genetic algorithm(GA) is used to identify these three parameters. Based on the theoretical analysis, the model of ISP was established, and the whole process of parameter tuning was designed based on GA. The Matlab/Simulink was used to verify the parameter tuning accuracy of GA. The results show small deviations exist between the parameters of the tuned parameters and the set value, and the accuracy is close to that of the parameter tuning at the stage. A series of experiments were carried out to validate the parameter tuning accuracy of GA. The experimental results show that the method can identify rotary inertia, damping coefficient and stiffness of rotary inertial stable platform with high accuracy and the effectiveness of parameters tuning method presented in this paper are validated.

**Key words:** inertial stabilized platform; angular vibration; parameter identification; genetic algorithm
**CLC number:** V249 **Document code:** A **DOI:** 10.3788/IRLA201948.S117004

# 惯性稳定平台固有特性参数辨识

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**摘 要:** 转动惯量、阻尼系数和刚度与惯性稳定平台的固有特性密切相关,将采用遗传算法对这三个参数进行辨识。从理论出发,建立惯性稳定平台的模型,基于遗传算法设计参数辨识的整个过程。通过仿真对基于遗传算法的参数辨识精度进行验证,结果表明辨识出来的参数值与设定值的偏差较小,与现阶段参数辨识所能达到精度相近。再通过实验对基于遗传算法的参数辨识精度进行验证,实验结果表明该方法可以较高精度的辨识出惯性稳定平台的转动惯量、阻尼系数和刚度,证实了所提出的辨识方法的有效性和工程实用意义。

**关键词:** 惯性稳定平台; 角振动; 参数辨识; 遗传算法

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**收稿日期:** 2018-07-19; **修订日期:** 2018-11-01

**基金项目:** 国家自然科学基金(11202010)

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## 0 Introduction

The inertial stability platform (ISP) can isolate carrier disturbances, and provide stability working environment for the load mounted on the ISP[1-2], so it is widely applied in the photoelectric detection system of vehicles, ships and aircraft. Due to the environment interference, vibration, friction, mass unbalances and other disturbance factors, the ISP will suffer the forced angular vibrations. In order to eliminate the forced angular vibrations of ISP[3], the inherent characteristic of the ISP are analyzed. Theoretical analysis in this paper reveals that the moment of inertia, damping coefficient and stiffness coefficient are closely connected with inherent characteristic of the ISP. The accuracy of those system parameters directly influence the analysis results of the inherent characteristic of the ISP and effectiveness of suppression of angular vibrations.

Foreign and domestic scholars have done extensive researches on method of identification of the moment of inertia. The moment of inertia and stiffness coefficient can be calculated by mathematical analysis and identification[4], and damping coefficient is usually obtained by modal analysis or empirical value [5]. In Ref. [6], one identification method of stiffness and damping of AMBs from rotor dynamic response due to imbalances was provided. Rotor bearing finite element model was built by MSC. Patran. The program was compiled by Matlab software based on the identification method of the imbalance response. In Ref. [7], the identified value is consequently used to calculate the gain of the speed controller and to calculate the load torque in the disturbance observer. In Ref. [8], identification method using the evaluation function is proposed for the yaw moment of inertia of the heavy-duty truck. The estimated yaw moment of inertia using the known tire slip angle has higher accuracy than using the unknown tire slip angle. In Ref. [9], the identifies moment of inertia of mechatronic servo systems based on the time average of the product of torque reference input and motor position. In Ref. [10], by means of measuring the vibration curve and processing the acquired data, the damping coefficient during turret running were obtained.

Based on a comprehensive papers review, there are few researches which aims at three kinds of parameter tuning, i.e., the moment of inertia, damping coefficient and stiffness coefficient of ISP. Due to disturbances derived from whatever the outer or inner of the ISP, there exists large differences between the real motion model and theoretical model. So this paper takes the method of the system identification to get the values of moment of inertia, damping coefficient and stiffness coefficient. This paper will use genetic algorithm (GA) to tune the three parameters of ISP[11]. Firstly, motion model of forced vibration is adopted under harmonic excitation, and the linear system identification method is combined with the motion model of ISP. Then, the identification of system parameter is realized by GA. The results of simulations and experiments show that the parameter tuning method based on GA is feasible for ISP.

## 1 Modeling of ISP

A series of models of ISP which contain motion model, motor drive model and frictional model are applied in theoretical analysis. And then, the models of these parts will be introduced separately.

### 1.1 Kinematical model of ISP

The motion model of ISP reveals the motion characteristics of the system and is also applied to tune the parameters about the moment of inertia, damping coefficient and stiffness of ISP. The deducing process of motion model is as follows.

The single axis ISP system is regarded as the single degree of freedom damped spring-mass system[12] and the model is shown in Fig.1. The steady-state motion differential equation of forced vibration of ISP under simple harmonic excitation is given by:

$$J\ddot{\theta}+C\dot{\theta}+K\theta=M\sin(\omega t) \quad (1)$$

Forced angle vibration is generated by external excitation of system which is generally function of time,, and periodic excitation can be extended into overlay of simple harmonic excitation by fourier series. So the study of the forced angle vibration of the single-degree-of-freedom system under the simple harmonic excitation is the basis of the study of damping of the system.

Following Eq.(1), the motion differential equation of single-degree-of-freedom angular vibration under simple harmonic excitation is given by:

$$J\ddot{\theta}+C\dot{\theta}+K\theta=Y_M \quad (2)$$

where $J$ is the moment of inertia of ISP; $C$ is damping coefficient of ISP; $K$ is stiffness coefficient of ISP; $Y_M$ is disturbance torque; $\omega$ is the frequency of excitation torque; and $\ddot{\theta}$, $\dot{\theta}$, $\theta$ is angular acceleration, angular velocity and angular displacement of ISP under the forced oscillation, respectively.

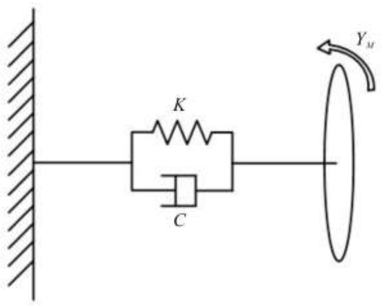


Fig.1 Single degree of freedom with the damping spring mass system

Supposing that $M\sin(\omega t)$ is the harmonic excitation of ISP:

$$Y_M=M\sin(\omega t) \quad (3)$$

According to Eq.(2) and Eq.(3), Eq.(4) is given by:

$$J\ddot{\theta}+C\dot{\theta}+K\theta=M\sin(\omega t) \quad (4)$$

The laplace transform is carried out on both sides of sign of equality, and the transfer function of between output angle of ISP and the input torque is given by:

$$\frac{\theta(s)}{M(s)}=\frac{1}{Js^2+Cs+K} \quad (5)$$

According to Eq.(5), the transfer function of ISP is mainly determined by the three parameters: $J$, $C$ and $K$. To analyze the inherent characteristics of ISP, the moment of inertia, damping coefficient and stiffness of ISP need to be tuned.

### 1.2 Modeling of motor drive system

As shown above, the process of kinematics modeling of ISP is given, and as follows, the motor drive system is based on the model of motor drive system in Ref.[13].

Gears are mounted between the motor and gimbals of ISP to drive gimbals indirectly, which is closely related to the direct driving. An indirect driving model of motor and gear drive can be built based on direct drive model. As Fig.2 shows, the equivalent circuit of direct current(DC) torque motor is given.

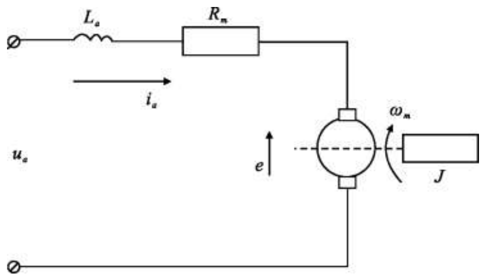


Fig.2 DC torque motor equivalent circuit

As Eq. (6) shows, the moment equilibrium equations of the motor is given:

$$J\frac{d\omega_m}{dt}=M_m-M_d \quad (6)$$

where $M_m$ is output torque of motor; $\omega_m$ is rotational angular velocities of motor; $J=J_m+J_L$, $J_m$, $J_L$ is the rotors and of moment of inertia of the load of motor.

As shown in Fig.3, the model of the between motor and ISP in the direct drive mode is given based on the Eq.(5) and Eq.(6) and the response speed and control precision are high in this way.

Where $R_m$ is armature resistance of motor; $C_m$ is torque coefficient of motor; $T_e=\frac{L_a}{R_m}$ is electric time constant of motor; $M_d$ is external interference of ISP; $J$ is the moment of inertia of ISP; $C$ is damping coefficient of ISP; $K$ is stiffness of ISP.

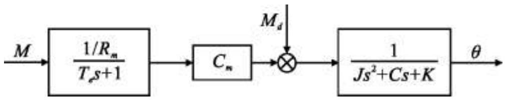


Fig.3 Motor and moment of inertial stability platform model

### 1.3 Friction model

The actual ISP is affected by external friction, so it is necessary to establish friction model. Stribeck model can describe the static friction, kinetic friction and friction decreases with the increase of speed when low speed movement, so this paper uses the Stribeck model to simulate the friction of ISP system modeling. According to the literature[14-15], the theoretical relationship of the model is shown in Eq.(7):

$$M=[M_c+(M_s-M_c)e^{-\left(\frac{\omega}{\omega_s}\right)^2}]\mathrm{sgn}(\omega)+\sigma\omega \tag{7}$$

where $M_c$ is Coulomb Friction moment; $M_s$ is maximal static friction torque; $\omega$ is the relative angular velocity between the contact surfaces; $\sigma$ is viscous friction coefficient; $\omega_s$ is velocity of Stribeck. Equation (7) which takes into account the static friction, Coulomb′s Friction, viscous friction and the Stribeck effect at low speed, which can illustrate the friction of ISP. Therefore, in this paper, the friction model of Eq.(7) is adopted, and the relation between relative velocity and friction moment is shown in Fig.4.

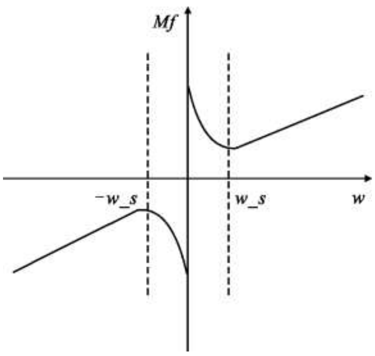


Fig.4 Friction model

## 2 Parameter identification and simulation verification based on genetic algorithm

### 2.1 Genetic algorithm recognizes the parameters of ISP

It is necessary to select the proper identification method to tune the parameters of the moment of inertia, damping coefficient and stiffness of ISP. The GA simulates the process of natural selection of Darwinian evolution and the computational model of the biological evolution of the genetic mechanism. It is a method to search the optimal solution by simulating the natural evolution process. It has the characteristics of simple universal, strong robustness and suitable for multi-parameter condition. In this paper, the formula of identification is (5), the formula has three parameters need to be identified, for this kind of static parameters identification, adopts the GA can get better effect[16]. So this paper adopts GA to tune the parameters of moment of inertia, damping coefficient and stiffness of ISP.

As Eq.(4) shows, a linear equation is given by:

$$\begin{cases} X=[J,C,K]^{\mathrm{T}} \\ H_k=[\ddot{\theta}_k,\dot{\theta}_k,\theta_k] \end{cases} \tag{8}$$

In Eq. (8), $k$ is the sampling moment and the matrix expressions is given by:

$$Y_{M_k}=H_k\cdot X_k \tag{9}$$

The estimate of $\hat{X}$ is $X$, and the estimated error $V_k$ is given by:

$$V_k=Y_{M_k}-H_k\cdot\hat{X}_k \tag{10}$$

After the $r$ sampling:

$$V_{k+r}=Y_{M_{k+r}}-H_{k+r}\cdot\hat{X} \tag{11}$$

When the GA is applied to tune parameters, the objective function is given by:

$$J=\sum_{i=1}^{n}e^2(k) \tag{12}$$

where $e(k)$ is the difference at $k$ moment. When the parameters of the simulation, model are consistent with the actual control objects, the value of $J$ goes to zero, and the target of parameters tuning is also the optimization of the minimum value of the objective function. According to the above analysis, fitness function is given by:

$$f=\frac{1/J_i}{\sum_{i=1}^{m}(1/J_i)} \tag{13}$$

where $J_i$ is the value of the objective function for a set of parameters. The population is 100, the maximum evolution generations is 200, the crossover probability is 0.7, and the variation probability is 0.1. After the GA identifies the parameters, a judgment parameter $J_{dec}$ is applied to determine whether parameters tuning is successful or not. When $J$ satisfies the following:

$$J<J_{dec} \tag{14}$$

where $J_{dec}$ is a definite value, which is determined by the actual system.

To sum up, a method is proposed to tune a set of parameters for moment of inertia, damping coefficient and stiffness of ISP based on GA in this paper.

### 2.2 Simulation analysis of parameter identification

This paper will use genetic algorithm to identify the model of ISP. In the process of parameters tuning, the disturbance torque should meet the requirements of ISP work, which is determined on the basis of the frequency and amplitude of the normal running of ISP. Then the angle, angular velocity and angular acceleration of ISP should be measured. Finally, the moment of inertia, damping coefficient and stiffness of ISP are identified by GA. The flow chart of parameter tuning is shown in Fig.5.

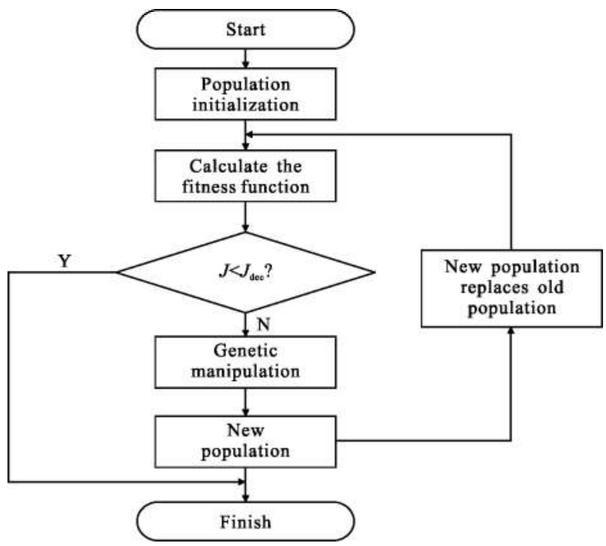


Fig.5 Flow chart of parameter tuning

On the basis of the process of parameter tuning in Fig.6, this paper limits the value of the target function of GA[17]. If the results of the parameters tuning did not meet the requirements, can repeat the process of GA to identify the parameter until the objective function to achieve the ideal value range, so that this process can guarantee the accuracy of the identification results.

The output of the normal work of ISP has certain scope, such as the angle of ISP should be less than ±10°, and the common frequency of work is mainly distributed in 0-20 Hz. Therefore, some restrictions are imposed on the disturbance torque of the ISP and the frequency and amplitude range of the normal work of ISP are chosen.

In order to ensure the reliability of the parameters tuning, multiple groups disturbance torque are applied to experiments validation and eliminate the multi-source disturbance of ISP. Figure 6 shows the external disturbance signal of the inertial stabilization platform.

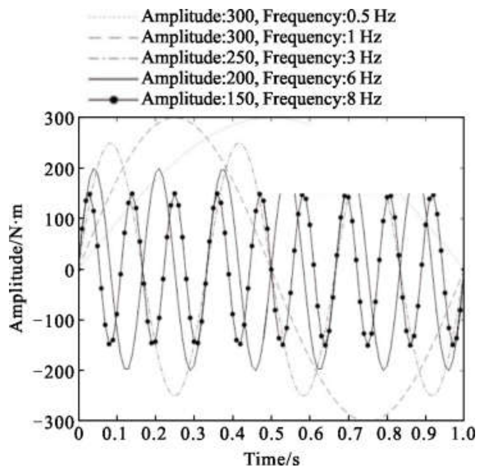


Fig.6 External disturbance signal of inertial stabilization platform

The general expression of the external disturbance signal of ISP is: $x(t)=A\sin(2\pi\omega t)$. Where $A$ is the amplitude of the disturbance torque; $\omega$ is the frequency of disturbance torque. The five sets of disturbance torque which choose different amplitudes: 300, 250, 200, 150 N·m, and different frequencies: 0.5, 1, 3, 6, 9 Hz, are given by: $x(t)=300\sin(2\pi\times0.5t)$,

$x(t)=300\sin(2\pi\times t)$, $x(t)=250\sin(2\pi\times 3t)$, $x(t)=200\sin(2\pi\times 6t)$, $x(t)=150\sin(2\pi\times 9t)$. The moment signal input of ISP contains multiple signals of different amplitude and frequency, which can guarantee the reliability of the identification results. The angle output value of ISP is shown in Fig.7.

Figure 7 shows the angles of ISP with the different amplitude and frequency of torque disturbance torque. The parameters of moment of inertia, damping coefficient and stiffness of identification results can be obtained by gathering the angle of ISP, combining with the Eq.(12) and Eq.(13) and parameter tuning showed in Fig.5. The results of parameter tuning are showed in Tab.1. The maximum error in Tab.1 is that the formula is:

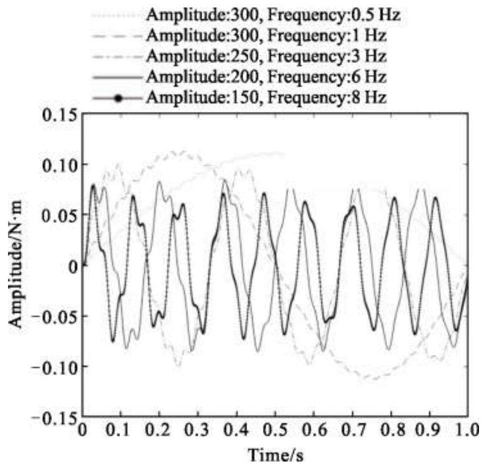


Fig.7 Angular output value of the moment of inertial stable platform

$$Max\_Error=\frac{\mathrm{Max}(|Measurement\_value-Reference\_value|)}{Reference\_value} \tag{15}$$

where *Max_Error* is the maximum measurement error; *Measurement_value* is parameter identification result; *Reference_value* is reference value of the parameter.

**Tab.1 Parameters identification results based on simulation**

| System parameter | Rotary inertia /kg·m$^2$ | Damping coefficient /N·m·s·rad$^{-1}$ | Stiffness /N·m·rad$^{-1}$ |
|---|---|---|---|
| Reference value | 0.02 | 0.045 | 677.3 |
| 0.5 Hz | 0.020 12 | 0.045 32 | 679.156 |
| 1 Hz | 0.019 88 | 0.044 81 | 677.861 |
| 3 Hz | 0.019 81 | 0.044 63 | 678.264 |
| 6 Hz | 0.020 18 | 0.045 41 | 676.812 |
| 9 Hz | 0.019 84 | 0.044 73 | 675.032 |
| Maximum error | 0.95% | 0.91% | 0.33% |

By comparing the tuning parameters results of five groups of different disturbance torque, it can be found that the values of parameters tuning are is smaller than the values of the theoretical model. The maximum error only is 0.95%, which meets the current accuracy requirements. It can be concluded that the accuracy of the parameters tuning results based on GA can meet the actual needs of the project.

## 3 Experimental verification

In this paper, the multi-group experiments were carried out based on an ISP to further verify the practicability of the proposed identification method in engineering. In order to guarantee the reliability of the identification results, multi-group signals with different frequency and amplitude were chosen as the disturbance torque of ISP. The identification principle of ISP system is shown in Fig.8.

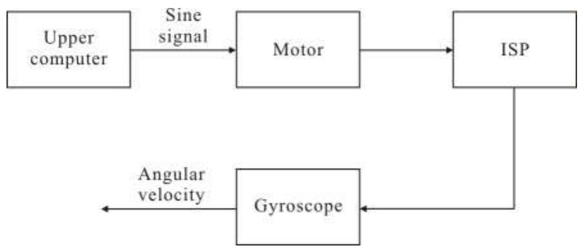


Fig.8 Identification principle of moment of inertial stable platform system

The upper computer is applied to control ISP and the output sinusoidal signal is applied to control the motor. The output torque of motor is used to control ISP movement, and the angular velocity of ISP is obtained by the gyroscope[18]. Then the angle and angular acceleration are calculated based on the angular velocity. The gyroscope′s measurement accuracy is 0.05 (°)/s, which can meet the measurement requirements. The above is the basic flow of the whole experiment. The physical picture of ISP is shown in Fig.9.

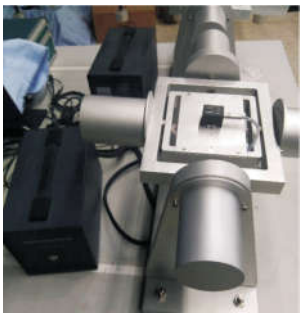

Fig.9 Image of moment of inertial stability platform

The measured angle, angular velocity and angular acceleration data are filtered, and then the inertia, damping coefficient and stiffness of the inertial stable platform are identified by genetic algorithm. The number of populations of the identification algorithm is 500, the maximum evolution algebra is 600, the probability of hybridization is 0.8, and the probability of mutation is 0.05. Through the identification process of Fig.5, the maximum error of the identification is calculated according to Eq. (15), and the obtained result is shown in Tab.2.

**Tab.2 Parameters identification results based on experiment**

| System parameter | Rotary inertia /kg·m$^2$ | Damping coefficient /N·m·s·rad$^{-1}$ | Stiffness /N·m·rad$^{-1}$ |
|---|---|---|---|
| Reference value | 0.020 2 | 0.045 4 | 674.325 |
| 0.5 Hz | 0.020 3 | 0.045 1 | 677.301 |
| 1 Hz | 0.020 8 | 0.046 1 | 679.145 |
| 3 Hz | 0.019 6 | 0.045 6 | 670.754 |
| 6 Hz | 0.019 7 | 0.044 8 | 668.015 |
| 9 Hz | 0.020 6 | 0.045 3 | 676.412 |
| Maximum error | 2.97% | 2.86% | 1.65% |

Based on Tab.2, it can be found that the identification results of the experiment are similar to the reference value of ISP under different disturbance torque, and the maximum error only 2.97%. Present the precision of parameter tuning is superior to 5%, which has reached the level of precision of this paper. It is proved that the process of GA is suitable for engineering practice and the identification results meet the engineering requirements.

## 4 Conclusions

This paper presents GA to tune the moment of inertia, damping coefficient and stiffness of ISP:

(1) Based on the theory, ISP model is established and the whole parameter tuning process is designed based on GA. Some changes are adopted to the GA to restrict the value of the target function and improve the accuracy of the identification results.

(2) The accuracy of GA is verified by simulation. Under different disturbance torque, the values of parameter tuning based on GA are close to reference value.

(3) A series of experiments were carried out to verify the theoretical analyses of the parameter tuning and the experimental results show that the accuracy of the parameter tuning based on GA meets the current engineering requirements.

Based on the above research, it can be concluded that the method based on GA to tune the inherent characteristic parameters of ISP is effective and feasible.

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