The Design Research of the Indigenous Steering Gear

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Abstract:With the development of the robot industry, the requirements of the joint actuator are improved. The steering gear becomes the first choice of the joint actuator, which has the characteristics of a modular, high integration, Small volume. However, there are universal problems of the steering gear in the domestic market, that torque is too small and rotation angle range is only 120 degrees. This paper adopts the method of contrast analysis of the influence the steering performance of a series of parameters for optimization design of steering gear. Through the drive scheme design, structure design, precision analysis and engineering drawings to finish the design work. Harmonic reducer is used to realize the steering gear of high torque output function; The non contact magnetic encoder is chosen to detect the rotation angle and improve the positioning accuracy and expand the range of rotation angle; The three-loop control is used to improve the response speed and accuracy of the motor. This paper mainly introduces the present situation of domestic research and the design of each module, and gives the concrete scheme of mechanical structure, hardware circuit and software design.

Key words:Optimization design.Harmonic reducer.Non contact magnetic encoder

0 INTRODUCTION [1]

The 21st century is an information technology, modular robot era of integration mechanism requires relatively improved. And now steering products on the domestic market can not simultaneously have high torque, small size and small weight. When the load is too large, small structural strength easily cause damage to the reduction gear, and even damage along with other agencies. At present, domestic high-torque servo mostly in the research stage, and domestic sale related rotation angle of the steering gear, steering angle through small retrofit come. This modification makes private servo appear decreased stability, position accuracy decreased structural strength loss and other problems. [1] After the servos on the market at home and abroad were compared found that the domestic output torque servos, position accuracy, stability are much lower than the imported steering gear. But imports steering gear has high prices, warranty difficulties and other shortcomings. This paper presents a new type of steering gear. It uses a brushless DC motor [2]and unique position detection mode and deceleration mode, and has a low price, high practical value and broad application prospects.

1 NEW TYPE OF STEERING GEAR DESIGN

Design of the new steering gear including that selection of the motor, reducer selection, the shape of shell design and so on.

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1.1 Motor Selection

Based applications and different uses, the choice of servo motor variety, including brushed DC motors, brushless DC motors, brushless flat motors and torque motors. Since the brushless DC motor using electronic commutation, no mechanical commutator and brush contact structure thereof. Fever in external windings, heat easily. At the same time has a high torque / inertia ratio value to provide greater output power, long life, high reliability and speed, thus obtaining more widely used in the production of model aircraft ducted serious heat in. FIG. 1 is a brushless DC motor mechanical characteristics at the rated voltage. Brushless DC motor stall torque is generally 3 to 10 times the rated torque, according to need and application conditions can be done even more than 20 times, so the brushless DC motor with strong overload. [2-3]

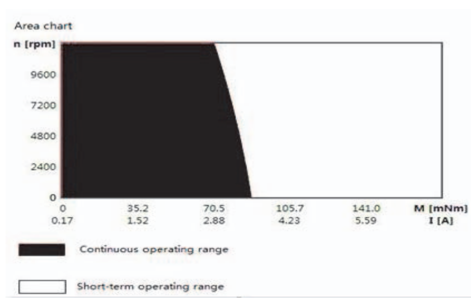

Figure 1: Model of a brushless DC motor mechanical properties

Therefore, according to the actual desired output torque and volumetric weight into account other factors, we chose a T-motor company brushless DC motor, model:U7KV280. The main performance parameters in Table 1.

Table 1. brushless DC motor performance parameters

Rated voltage/V	24
Rated speed/rpm	10080
Current Rating /A	40
Rated torque (maximum continuous speed)/Nm	1.2
Speed / torque slope /rpm/mNm	8.4
Bearing Type	Ball bearing
weight /g	255

1.2 Reducer Selection

Commonly used in accordance with the structural characteristics of the gear unit can be divided into: straight gear reducer, helical gear reducer, bevel gear reducer, worm gear reducer, planetary gear reducer and harmonic and so on. Table 2 for these types of reducer a simple comparison. [4-5]

Table 2 Comparison of various types of gear unit

Deceleration principle	Pros and cons
Spur gear reducer	Strong bearing capacity, reduction ratio is not big, bulky
Helical gear units	Start a smooth, stable transmission, large transmission torque
Bevel gear reducer	Load capacity, low noise, install complex
Worm reducer	compact structure, large reduction ratio
Planetary gear	smooth, high efficiency, large radial dimension
Harmonic reducer	compact structure, large reduction ratio, the process is complicated and costly

Factors to consider when choosing reducer main volume, torque, weight, price. As the general use of basic materials reducer or less, it is found to approximately proportional to the size and weight. So choose reducer considerations torque / weight ratio as well as the price of these two factors, giving Table 3 below.

Table 3 common types of the weight of the gear unit torque parameters

Reducer	Output torque/Nm	Weight g	torque / weight Nm/g*10^-3
Planetary gear	15	460	32.61
Spur gear reducer	2.032	62	32.77
Harmonic reducer	18	345	52.17
Worm	10.2	1200	8.5
Cycloid	44.2	855	51.69

As Table 3 shows, the commonly used reducer on the market to cycloid and harmonic reducer torque than the maximum weight, while taking into account micro cycloid reducer domestic market is difficult to find, and the cost higher. It was chosen as the final reduction gear reducer harmonic scheme. According to the above reasons we chose Leaderdrive harmonic reducer, model: LHD-14-100-I.

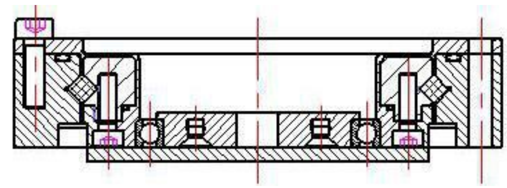

Figure 2: LHD-15-100-I harmonic reducer

The harmonic reducer model parameters as follows.

Table 4 Harmonic Reducer

	Moment Mb/Nm	radial force Fr/Nm	axial force Fa/Nm
Allows instantaneous value	160	830	830
Commitment allowable value	80	490	490
The design value of	41	270	270

1.3 New Type Of Steering Gear Design

1.3.1 Geometry Design

Commonly used high-strength materials 1Cr18Ni9Ti stainless steel hardness and 7075 aluminum alloy, to ensure a stable digital motor structure, try to reduce the weight, so the final choice of material is 7075 aluminum alloy as the main material. Materials, physical properties as shown in Table 5.

Table 5 Material Physical Properties

	Strong tensile	yield strength	modulus	Hardness /HB
Material	Degree /Mpa	Degree /Mpa	Amount /Gpa	
1Cr18Ni9Ti	≥550	≥220	None	≤187
7075	524	445	71	150

Meanwhile, the digital output of the motor and gear housing are made of a flange design, both to provide a convenient way for the user to install, and flat key connection can transfer more torque compared.

Screw thread transmission torque available capacity to withstand shear forces represented. If subjected to a shear force of 490N, look-up table for the ultimate strength of the bolts 10.9 209MPa. Screw shaft shear strength conditions:

$$\tau = \frac{Fs}{\frac{\pi}{4} d_0^2} = \frac{490Nm}{\frac{\pi}{4} \times 8 \times 2mm^2} = 4.87MPa \quad (1)$$

And allowable shear strength:

$$[\tau] = \frac{\sigma s}{St} = 83.6MPa \geq \tau \quad (2)$$

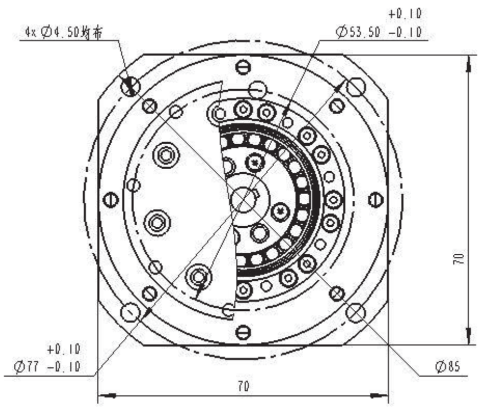

Figure 3: Digital motor output

Distribution on 1.ϕ77 round 4 fixing holes

Distribution on 2.ϕ53.5 round mounting holes 8 outputs

1.3.2 Output Torque Design

Figure 4 is an external load is applied Fig.

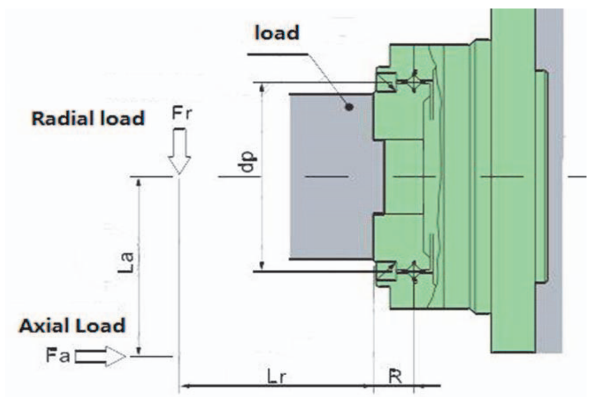

Figure 4: The role of external load diagram

For the harmonic reducer, the maximum static moment equation should be met:

$$M_{\max} = Fr_{\max} \times (Lr + R) + Fa_{\max} \times La \leq Mc \quad (3)$$

$$Mc = 41Nm \quad (4)$$

Table 4 can be obtained by:

$$M_{\max} = 270 \times (Lr + 10) + 270 \times 26 \quad (5)$$

So the maximum allowable $[Lr] = 187\text{mm}$

1.3.3 New Type Of Steering Gear Structure Analysis

This article uses the ANSYS Workbench module for new steering structure analysis. Workbench is mainly used for analysis of physical fields to deliver optimized automatic meshing, simulation analysis, improved simulation efficiency. Since the output torque when the steering shaft is the main subject of the tangential force, so the cut-axis force calculation and analysis. Axis by the tangential force:

τ_T - Axis tangential force MPa

T - Transmitting torque shaft Nmm^2

W_T -Shaft torsional section modulus mm^3

P -Transfer efficiency shaft kW

n - Shaft speed rpm

Solid shaft and again:：

$$W_T = \frac{\pi d^3}{16} \approx 0.2d^2 = 672.8mm^2 \quad (6)$$

Also, because the choice of material for 7075, so get allowable stress

$$[\tau_T] = 15 \sim 25MPa \quad (7)$$

Take$[\tau_T] = 16MPa$

So draw:

$$\frac{P}{n} = 0.11 \times 10^{-2} kW / rpm$$

2.DESIGN AND IMPLEMENTATION OF MOTOR CONTROL

2.1 Design Of Control Electronics

In the servo control software modules, we use two single-chip timer module, wherein a timer control current sampling period, another way to control the timer control cycle steering control system. Both timers favor stability of the system. In a control cycle, the system first reads the magnetic encoder pulse number, and reads three-way phase current value by analog to digital conversion module. At this point the microcontroller judge whether the current value exceeds the current limit protection, if the threshold is exceeded, the system will enter the protection mechanism by cutting output to protect the security of hardware circuitry and motors.

The system uses CAN protocol for communication, the system according to the position command obtained from the CAN interrupt, updating the current control cycle a given location, the value input to the three closed-loop control module. The output of the closed loop system through pulse-width modulation (PWM) module driving motor is rotated into a specific location, to achieve the servo position control.

2.2 Driver Circuit Design

Currently on the market most of the control disc motor device is an electronic governor, did not form a closed-loop control, control accuracy is poor. And there is no feedback between the electronic governor and disc motor, this can easily lead to damage to the electronic governor and a disc motor. Electronic governor has a high cost, bulky, energy shortcomings, not suitable for high-precision motor integrated disk drive.

We use self-developed brushless motor disc drive. Disc motor controller ARM-M3 series monolithic STM32F103C8T6. The chip is enhanced chip, which ensures strict accordance microcontroller logic operation. Microcontroller through the powerful peripherals control of peripheral circuit off, thus ensuring stable operation of the motor disc.

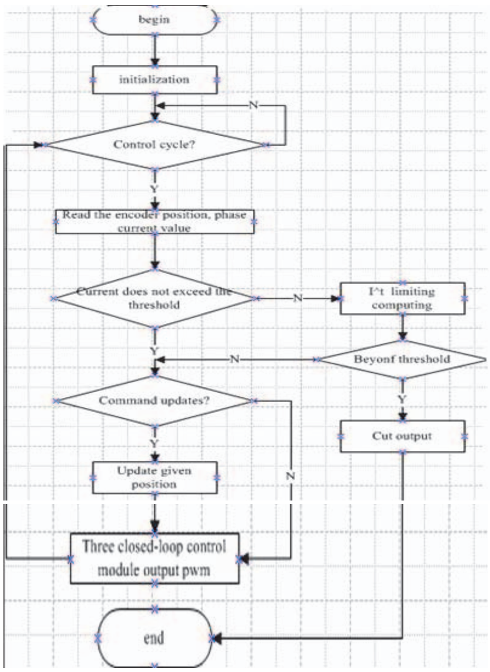

Figure 5: The control system flowchart

Square wave commutation, sinusoidal commutation are two common driver control brushless motor commutation mode. The former has a larger torque ripple, low quality control shortcomings. The latter was in response to bandwidth limitations, can not be achieved in the case of high-speed movement precise sine wave tracking. We used field-oriented control theory and space vector modulation (SVPWM) technology, the stator current decomposition coordinate transformation to direct and quadrature axis. It enables individual control of flux and torque. It also implements the decoupling control of three-phase motor flux and torque. This control method not only enhance the efficiency of control, and can effectively inhibit the motor torque ripple and improve the level of control. In terms of torque ripple or a response bandwidth of our control we are better than the previous two. [11]

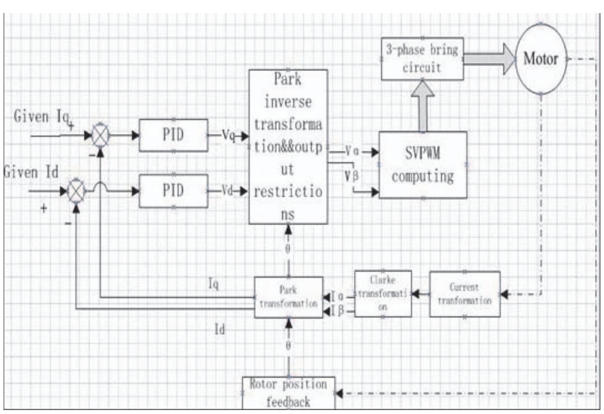

Figure 6: schematic field-oriented control

Figure 3.2 is a schematic diagram of field-oriented control, measure the actual two-phase current, according to Kirchhoff's law calculates the third phase current, three-phase current Clarke transformation to a stationary two-axis coordinate system α-β, to give orthogonal instantaneous current value ia, ib.

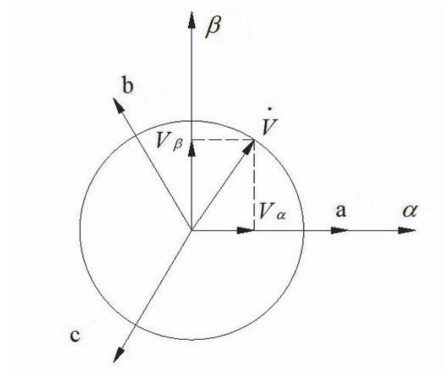

Figure 7: Clarke and Park transformation

Its conversion formula is as follows

$$\begin{cases} i_\alpha = i_a \\ i_\beta = \dfrac{i_a + 2i_b}{\sqrt{3}} \end{cases} \tag{8}$$

Park by the current vector α-β coordinate transformation to convert the d-q coordinate system, so that the current is broken down into direct current and quadrature axis currents Id, Iq, specific formulas Park transformed as follows:

$$\begin{cases} I_d = i_\alpha \cos\theta + i_\beta \sin\theta \\ I_q = -i_\alpha \sin\theta + i_\beta \cos\theta \end{cases} \tag{9}$$

Orthogonal axis current is the current rotating orthogonal coordinate system, under steady state conditions, these two currents is constant. Enter them into the PID operation module to obtain an output Va, Vb, namely voltage vector motor.

Vector voltage d-q coordinate system conversion to α-β coordinate system, this process occurs after the current loop output voltage vector, Park inverse transformation is calculated as follows:

$$\begin{cases} V_\alpha = V_d \cos\theta - V_q \sin\theta \\ V_\beta = V_d \sin\theta + V_q \cos\theta \end{cases} \tag{10}$$

The quadrature voltage α-β coordinate system is converted to phase voltage vector. Calculated as follows:

$$\begin{cases} V_a = V_\alpha \\ V_b = \dfrac{-V_\alpha + \sqrt{3}V_\beta}{2} \\ V_c = \dfrac{-V_\alpha - \sqrt{3}V_\beta}{2} \end{cases} \tag{11}$$

Finally, SVPWM calculated phase voltage values to obtain new motor PWM duty cycle value, in order to achieve the smooth running of the motor.

2.3 Angle Control Implementation

2.3.1 The Choice Of Sensors

Accurate and reliable rotor position, accurate speed detection is essential for achieving high performance servo motor control. To obtain the rotor position and speed information, people usually install photoelectric encoder, rotary transformer, etc. encoder on the motor shaft. However, the volume of rotary transformer is too large, the photoelectric encoder can not tolerate a greater intensity of vibration, the working environment is limited. [6] magnetic encoder is a new encoder, which is based on the Hall effect and magnetoresistance effect, simple structure, small size, high impact resistance, high reliability, compared with the optical encoder, resolver, has unique advantages in the field of servo control caused widespread concern. [7-10]

Encoder chip using magnetic disc motor revolutions AS5045 series gathering momentum and the amount of rotation speed change, for implementing the closed-loop control of the disc motor speed, current, position. The chip uses a relatively non-contact measurement, each ring can remember 4096 pulses, greatly improve the measurement accuracy, improve the speed loop, current loop and position loop closed-loop control accuracy.

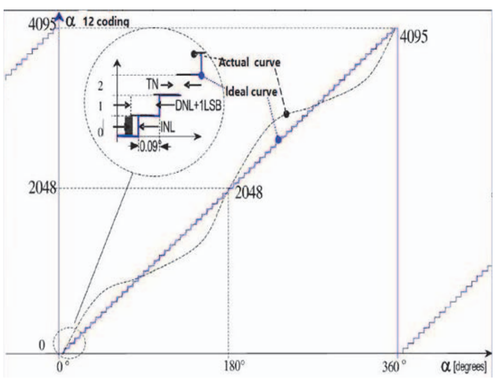

Figure 8: Chip integral and differential nonlinearity examples

2.3.2 Grade Sensor Installation

According AS5045 manual installation position of the magnet is shown below

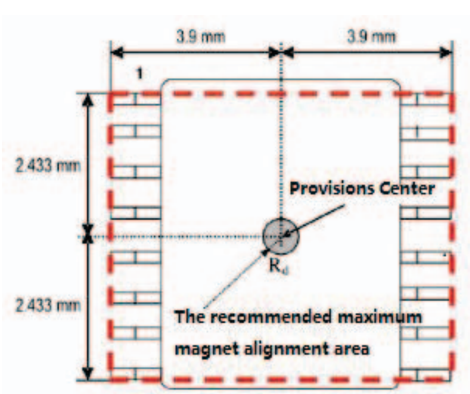

Figure 9: provisions chip center and magnet displacement radius center

By Gauss meter to detect the magnetic field strength along the radius of the concentric circle 1.1mm after installation

$$B\upsilon = \pm 45mT \sim \pm 75mT \qquad (12)$$

3.TEST OF POSITIONING ACCURACY

AS5045 chip is known to use every lap of 4096 pulses, is rotationally positioned digital motor test for the following conditions.

3.1 The Position of The Fixed Speed Deviation

Now set at 24V DC power supply for digital motor test, set the initial position of 1000 (actually 997), position of the random collection by between 10 to 10,000 rpm to obtain transfer data in the following figure.

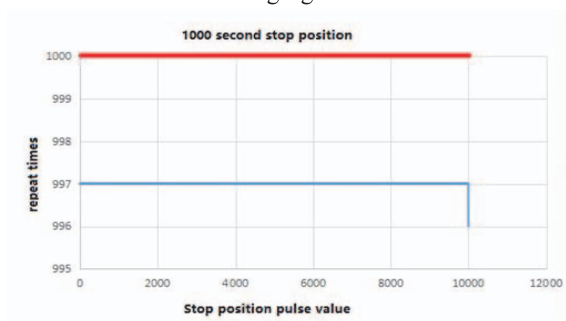

Figure 10. Repeat positioning accuracy fixed speeds

This number can be seen at the same voltage motor continuously rotating repeatability better.

3.2 The Location Accuracy of The Fixed Number of Turns

Now set at different test voltages turned 100 laps, the initial position is set to 1000 (actually 997), by 2V, 5V, 8V, 12V, 16V, 22V, 24V positioning accuracy testing voltage, The following figure obtained.

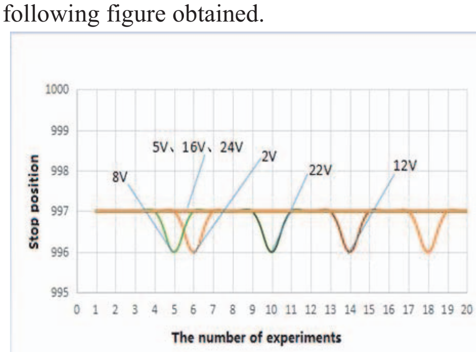

Figure 11: Repeatability stop position at different voltages

It can be seen that the digital motor at different voltages continuously rotating repeatability better.

3.3 Speed Characteristic

In each control cycle (0.5ms) pulse is given a certain value to obtain the actual motor speed digital, digital motor speed characteristic curve can be obtained as follows.

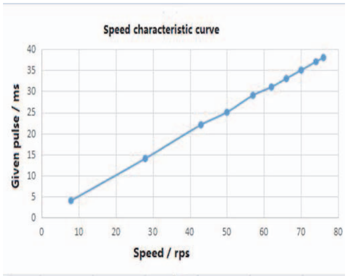

Figure 12: The number of motor speed curve

It can be seen that the digital motor speed characteristics stable.

4.THE PARAMETER COMPARISON OF DOMESTIC AND FOREGN EXCELLENT STEERING GEAR

In view of the domestic and foreign existing good steering gear parameters comparison, found the university applied in robot competition ROBOTIS OCservo steering gear and Korea DYNAMIXEL steering gear, form listed below:

Digital Motor studied in this paper the motor,reducer, encoder, drive together, using the mode control bus connected in series, traces simple. By comparing various aspects of the market more than the servo light.

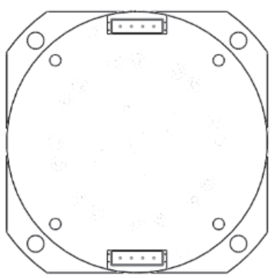

Figure 13:The trunk diagram of digital motor

Table 6: Comparison of domestic and foreign servo performance Parameters

	OCservo 2001	OCservo 801	H54-200 S500	Digital Motor
size /mm	78x44x79	62x34x36	54x54x126	70x70x76
Operating voltage /V	24	12	24	24
Continuous torque /N*m	20. 09	7. 55	44. 7	61
Weight /g	380	135	855	420
Resolution /°	0. 36	0. 15	0. 0007	0. 0009
Angle range/°	180	360°	360°	360°
Continuous Current /mA	30	30	1650	3500
Max Current /mA	3700	4800	9300	8500
Operating temperature /℃	10~80	10~80	5~55	10~80
No-load speed /rpm	55. 6	55	33. 1	48

5.CONCLUSION

(1) This design differs from traditional domestic digital servo motor, effectively improve the positioning accuracy, and the rotation angle range.

(2) integrated application of the deceleration mode, improved torque, making use of the servo surface as large as possible.

(3) an integrated whole, the steering gear ratio is the same as the cost of importing lower torque output, more suitable for the domestic market.

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