

# Trajectory operation and coordinated control of MATLAB manipulator in automobile manufacturing industry

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**Abstract.** The trajectory operation and coordinated control of the MATLAB manipulator have a positive impact on the automation development of the automobile manufacturing industry. In order to improve China's current automobile manufacturing MATLAB manipulator application technology in the industry, the screw tightening of the engine cylinder head in the automobile manufacturing industry was taken as an example in this paper. The MATLAB manipulator was designed, and the trajectory operation and coordination control precision of the engine cylinder head mechanical arm were analyzed. Results showed that the trajectory motion and coordination control precision of the robot arm were closely related to the actual demand. Moreover, the precision grade of the mechanical arm used in this study could meet the actual needs of the automobile manufacturing industry. The conclusions provide theoretical basis and reference for the development and improvement of the mechanical arm of other production links in the automobile manufacturing industry.

**Key words.** MATLAB manipulator, trajectory operation, coordinated control, automobile manufacturing industry.

## 1. Introduction

With the rapid development of the world economy, great progress has been made in all sectors of the world. With the continuous improvement of the industrial structure and related theories, the comprehensive level of various industries has been greatly improved. Nowadays, with the development of the new era, a variety of more advanced technologies begin to appear. Especially with the development of computer technology, many automated industrial patterns have been studied and applied to the actual production and life. The development of these new technologies has brought convenience and development for people's production and life, and made people's production and life more colorful. In the era of the development environment, the automobile industry is a relatively new industry, which has grad-

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ually become one of the important traffic tools in people's life and production, and played an important role in people's life. With the continuous progress of science and technology, some of the more innovative technologies are gradually applied to the actual automotive industry processing, which have brought important driving forces and positive impact for the further improvement of the automotive industry and the promotion of comprehensive strength. As one of the most important product of the rapid development of science and technology, the development of MATLAB manipulator technology has played a complementary and auxiliary role for the development of automobile manufacturing technology in the present era, and it has a certain impact on the improvement of manufacturing efficiency in the process of automobile manufacturing. In this paper, the main influences of the trajectory operation and coordinated control of MATLAB manipulator on automobile manufacturing technology are analyzed, so as to provide a theoretical basis and reference for the development of automobile manufacturing industry in our country.

## 2. State of the art

With the development of the times, the automobile has gradually become one of the most important means of transportation in people's daily life. With the increasing demand for automobiles, the automobile manufacturing industry has gradually become one of the important pillar industries in the world economic development [1]. In recent years, the inevitability of the development of automobile manufacturing industry makes many scholars consider the application of more innovative concepts and techniques to the actual production of automobiles and to form a more innovative model of development, so as to bring certain impetus to the development of the automobile manufacturing industry [2]. Transmission is one of the most important parts of the automobile manufacturing industry. Many researchers have begun to recognize the inevitability of the development of this manufacturing process. With the development of various innovative technologies, especially the computer technology, it has a positive impact on the upgrading of automation technology [3]. As a new type of automobile manufacturing automation technology, MATLAB manipulator has a certain impetus for the promotion of manufacturing efficiency and human resource saving in the process of automobile manufacturing. Many enterprises have already introduced the new technology into actual automobile manufacturing industry, and combined it with the actual production, so that the car industry can obtain greater development and progress [4].

### 2.1. Methodology

With China's entry into the new century, the dynamics and influence of reform and opening to the outside world have led to a great deal of progress and development in many industries in China. Especially in the manufacturing industry, taking the automobile industry as an example, China has become an important import and export country of automotive products in the world. With the introduction of new theories and technologies, the industry model and concept of automobile man-

ufacturing industry have become more mature and perfect, which gradually become an important pillar industry in China. With the rapid development of automobile manufacturing industry in China, a number of new technologies have been developed and applied to the actual production of automobile manufacturing. The manipulator technology based on MATLAB has gradually attracted the attention of some automobile manufacturing industries in our country. In China’s automotive industry, the application of MATLAB manipulator technology has gradually increased, and related theoretical research has made great progress [5]. However, with the rapid development of MATLAB manipulator technology in our country, the final application results are not satisfactory because of the relative weakness in some parts of the automobile manufacturing industry. For example, MATLAN manipulator technology is still relatively deficient in the manufacture and research and development of some auto parts in China’s automobile manufacturing industry, and the relative technical level is relatively low. A series of factors have resulted in poor production capacity for some of the more sophisticated parts of the automotive industry in China, and many cars have to be imported from other countries. It makes China’s automobile manufacturing and production subject to other countries, and the whole industry has the relatively high cost of production, which may cause China’s automobile manufacturing industry experiencing a bottleneck period. Some statistics believed that in 2015, for China’s automobile manufacturing industry, the local auto manufacturers only accounted for 5% in the sales volume of ten foreign auto manufacturers or enterprises, and the sales of related automotive products were shown in Fig. 1.

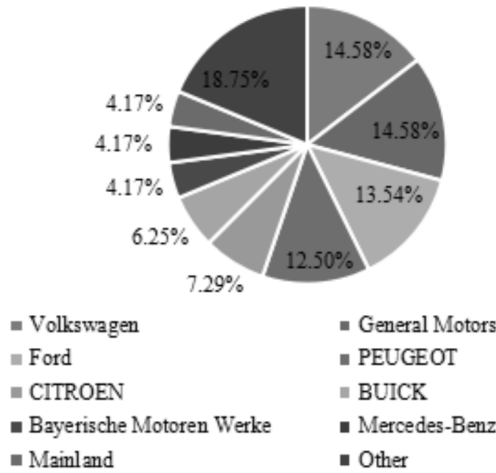


Fig. 1. Sales and marketing of China’s auto manufacturing industry in 2015

In this paper, on the basis of a clear awareness of the status quo of China’s automobile manufacturing industry, it is necessary to analyze and study the shortcomings of China’s auto manufacturing industry, so as to optimize the limitations of its development. In addition, it can reduce the gap of China’s automobile manufacturing industry and other foreign advanced enterprises, improve the competition ability

of China's automobile manufacturing industry, and make China get a foothold in the monopoly of the automobile manufacturing industry in developed countries in today's world [6]. This study will study and analyze the key technology and theory of MATLAB manipulator in China's automobile manufacturing industry, and then discuss the core part of it. On this basis, the main performance of MATLAB manipulator in automobile manufacturing industry is studied [7]. Then, this research will discuss the operation trajectory and coordination control system of MATLAB manipulator in the automobile manufacturing industry of our country, so as to confirm the research route of this research. The research directions are as follows.

(1) In this study, the current situation of automobile manufacturing industry in our country is analyzed by reading relevant data. The defects and shortcomings of MATLAB manipulator application in China's automobile manufacturing industry are summarized, and the key links and technologies that need to be solved are discussed.

(2) On the basis of a clear understanding of the related technologies and theories of robotic manipulators, the manipulator model is constructed by using the related mathematical models of forward and backward kinematics and dynamics used in the research of manipulator [8]. Through the analysis and discussion of the relevant data, we further optimize the trajectory operation system and coordinated control system of the MATLAB manipulator, so as to complete the following related experiments. The construction process of the relevant mathematical model theory is as follows.

The azimuth description model of each link of robot arm is

$${}^A_B R = [{}^A X_B {}^A Y_B {}^A Z_B] = \begin{bmatrix} n_x & n_y & n_z \\ o_x & o_y & o_z \\ a_x & a_y & a_z \end{bmatrix}, \quad (1)$$

where  ${}^A_B R$  is the rotation matrix of each component of the manipulator, and  $n$ ,  $o$ ,  $a$  are the projection components of different links in different directions [9], as shown in Fig. 2.

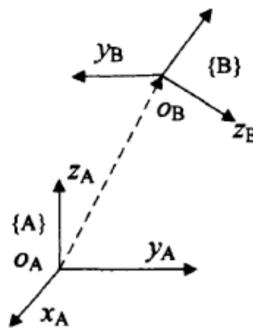


Fig. 2. Description of azimuth of different links in different directions

After setting up the parameters of the manipulator, the mathematical model is constructed based on the theory of forward kinematics. The model is constructed

as follows.

$${}^i_{i-1}T = \text{Rot}(X_{i-1}, \alpha_{i-1})\text{Trans}(X_{i-1}, \alpha_{i-1})\text{Trans}(X_{i-1}(Z_i, d_i)\text{Rot}(Z_i, \theta_i), \quad (2)$$

where  ${}^i_{i-1}T$  is the transformation matrix of the manipulator,  $X_i$  and  $Z_i$  belong to different links of the manipulator, respectively,  $\alpha_i$  and  $\theta_i$  represent the rotation angle of the robotic arm during the operation, and  $d_i$  represents the translational distance in the running of the manipulator.

On the basis of understanding the inverse kinematics and related parameters, in order to obtain a higher manipulator trajectory scheme, the related mathematical model of forward kinematics is further introduced [10]. The model design is

$${}^i_{i+1}T = {}^1T_2{}^2T_3{}^3T_4{}^4T_5{}^5T_6T \dots {}^i_{i+1}T. \quad (3)$$

(3) Finally, this study takes a car manufacturing industry in China as the research object. In view of the lack of automobile manufacturing in the operation process of the automobile manufacturing enterprise, more and more single robot arms are used only in the production process. It leads to low production efficiency and it cannot better meet the actual demand for automobile production. For this series of uncoordinated problems, further research is made on the trajectory operation and coordination control of the multi-robot manipulator, so as to provide a solution for the development of the entire automotive industry.

### 3. Results analysis and discussion

In order to improve the comprehensive strength of China's automobile manufacturing industry, many researchers in China have begun to apply the MATLAB mechanical arm technology to the actual automobile production (see Fig. 3).

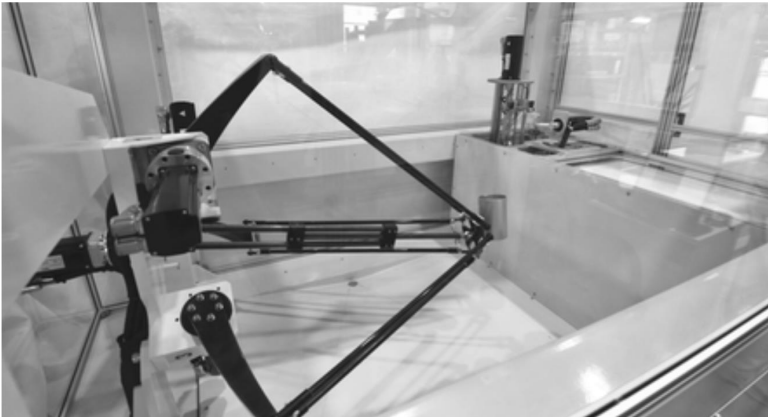


Fig. 3. Development and application of MATLAB manipulator

However, due to the relatively low level of research on this theory in our country, the key technology of MATLAB manipulator is still insufficient and defective [11].

Based on the investigation of related data and automobile manufacturing industry, the development trend and research center of mechanical arm technology in our country are summarized as follows [12]:

(1) In order to better combine the mechanical arm with the car in the manufacturing process and form a modular operation mechanism, it is necessary to improve the material of the manipulator so as to improve the overall practicability of the manipulator and improve the bearing capacity of the manipulator.

(2) With the continuous development of automotive technology, the demand for some more sophisticated parts has begun to increase. This requires the design of manipulator in the related links may need to optimize the processing, so that the manipulator has a certain degree of flexibility, and achieve the same hand or beyond the actual operation ability.

(3) It can improve the accuracy and stability of the manipulator in the automotive manufacturing industry, so that the final production of related automotive components can reach the world advanced level.

(4) On the basis of the rapid development of computer technology and sensors, the organic combination of robot arm and human being is further realized, so that the manipulator can better recognize the needs of the entire industry, provide some planning for subsequent development, and improve the efficiency of the final automobile industry.

This research mainly focuses on the current status of the important parts-engine in the automobile manufacturing industry. As an important part of the automobile, the engine has a very important influence on the operation of the automobile. Only with a higher performance of the engine can make the car have higher running speed, so that the level of China's automobile industry has been greater development and progress [13]. In the traditional automobile manufacturing process, the fastening of the engine bolts is done manually. However, the efficiency of manual operation is relatively low, and the process of human operation may be affected by some human factors, it may have a negative impact on the final quality of cars and ultimately weaken China's automobile influence [14]. Therefore, the main operation process of the robot arm object is to fix the bolt of the cylinder head of the engine [15]. The main object of the study was the four-cylinder engine in the automobile production. The 3D model and size are shown in Fig. 4. Before using the manipulator for automatic assembly, the engine enters a fixed mounting position. In addition, the bolt part of the cylinder head is manually installed with screws, and the final installation task is finished by the automatic rotation of the manipulator.

In the study, the installation requirements of the cylinder head installation of the automotive engine types involved in other references are summarized. The results are shown in Table 1, which can be used for the index design of the follow-up manipulator, so as to further improve the final applicability of the manipulator involved.

Table 1. Assembly requirements for some engine cylinder heads

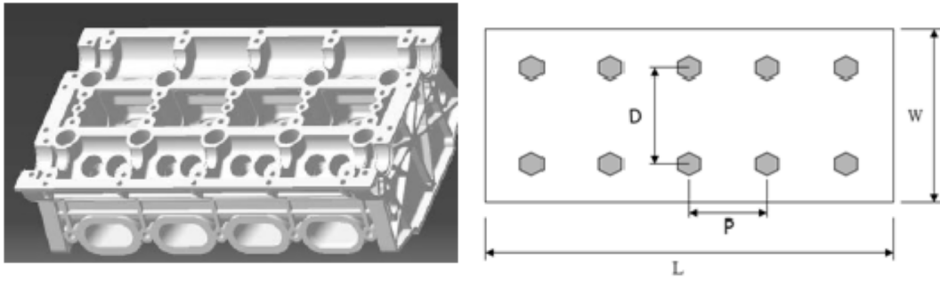


Fig. 4. 3D appearance and dimensions of a four-cylinder engine for study

Model	Cummins 6BT	6114	EQ6102	6108ZQ
Bore	102 mm	114 mm	102 mm	108 mm
Bolt longitudinal spacing	85 mm	101 mm	85 mm	95 mm
Target torque	165~180 Nm	210~230 Nm	150~165 Nm	175~190 Nm
Tightening process	120 Nm + 90°	142 Nm + 100°	90 Nm + 80°	110 Nm + 90°

On the basis of summarizing and describing the installation process of other automotive engine types and cylinder heads, the parameters of the manipulator are set by summarizing the related data, so as to lay a foundation for the follow-up manipulator trajectory operation and coordination control system optimization. By using the formula mentioned above, the parameters of the relevant manipulator links used to study the screw rotation of the automotive engine cylinder head are calculated, as shown in Table 2.

Table 2. Link  $D - H$  parameter setting of the manipulator

n	$a_{n-1}$ (mm)	$\alpha_{n-1}$ (°)	$d_n$ (mm)	$\theta_n$ (°)	$\theta_n$ range (°)
1	0	0	0	$\theta_1$	-170~170
2	170	-90	0	$\theta_2$	-85~120
3	560	0	0	$\theta_3$	-170~85
4	155	-90	365	$\theta_4$	-180~+180
5	0	90	0	$\theta_5$	-135~135
6	0	-90	0	$\theta_6$	-360~360

The design of manipulator in the tightening process of automobile engine cylinder head is studied. Firstly, the force of the cylinder head before and after the bolt tightening is analyzed. In order to make the overall stress of the cylinder head of the engine more balanced, not cause the shape change of the cylinder head, and cause material damage during tightening of cylinder head bolt, two feasible tightening sequences are designed for the bolt tightening sequence of the manipulator, as shown

in Fig. 5. The method of bolt tightening used in this study is the torque-angle method.

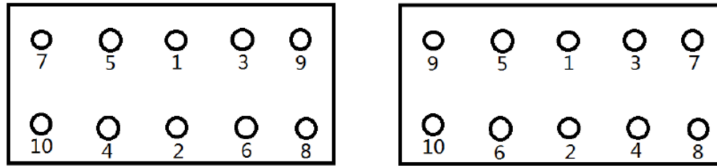


Fig. 5. Tightening sequence of engine cylinder head bolts

The parameters of the mechanical arm are set up, and the screwing order and tightening method of the engine cylinder head bolt are clearly defined. In this study, through the calculation of the relevant mechanical model, the model of the cylinder head bolt screwing machine of the automobile engine is designed, as shown in Fig. 6.

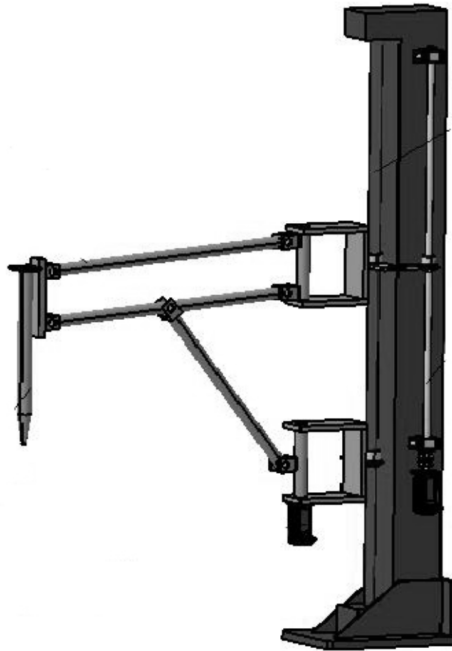


Fig. 6. Manipulator model of cylinder head bolt screwing of automobile engine

Finally, the application and analysis of the trajectory and coordination control accuracy of the manipulator designed are carried out. The results are shown in Table 3. The results show that the trajectory motion and coordination control precision of the manipulator are closely related to the actual demand. The different precision grades of this kind of mechanical arm can meet the actual demand in the automobile manufacturing industry.

Table 3. Precision operation results of trajectory motion and coordinated control of manipulator in different demands



Accuracy class		Lead accuracy of mechanical table operation ( $\mu\text{m}$ )									
		C0		C1		C2		C3		C4	
ELTP (mm)		RE	VV	RE	VV	RE	VV	RE	VV	RE	VV
>100	$\leq 200$	3.5	3	4.5	5	7	7	10	8	20	18
>200	$\leq 315$	4	4	6	5	8	7	12	8	23	18
>315	$\leq 400$	5	4	7	5	9	7	13	10	25	20
>400	$\leq 500$	6	4	8	5	10	7	15	10	27	20
>500	$\leq 630$	6	4	9	6	11	8	16	12	30	23
>630	$\leq 800$	7	5	10	7	13	9	18	13	35	25
>800	$\leq 1000$	8	6	11	8	15	10	21	15	40	27
>1000	$\leq 1200$	9	6	13	9	18	11	24	16	46	30

Note: ELTP—Effective length of thread part, RE—Running error, VV—Variable value

## 4. Conclusion

Nowadays, the demands for real life goods have increased the scale of production in manufacturing industry. As an important role in people's production and life, the development of the manufacturing industry has been increasing year by year. There is no doubt that the development of MATLAB manipulator technology will push the automobile industry. However, due to the lack of research and development of the manipulator technology in our country, there are still some phenomena of imperfect theory and immature development in the actual automobile manufacturing and production. In order to perfect and research the related theory, the related theories of trajectory operation and coordinated control of MATLAB manipulator were summarized in this paper. On the basis of understanding the theories, the tightening process of engine cylinder head in automobile production process was studied as an actual case. In the research, the parameters of the trajectory, operation and coordinated control of the MATLAB robot arm used in the engine cylinder head were set up, and the model was constructed. Finally, through the precision analysis of the mechanical arm model, it was found that this kind of robot arm could meet the needs of actual production. In this research, the manipulator of the engine cylinder head was simply designed with few levels and some defects. However, this study could still be used as a reference for the development of other manipulator.

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