한국기계가공학회지, 제17권, 제5호, pp.1∼7(2018.10) ISSN 1598-6721(Print)
Journal of the Korean Society of Manufacturing Process Engineers, Vol. 17, No. 5, pp.1~7(2018.10) ISSN 2288-0771(Online)

https://doi.org/10.14775/ksmpe.2018.17.5.001

Simulation Analysis of Flexible Track Drilling Machines Based on ADAMS

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ADAMS 기반의 플렉시블 트랙 드릴링 머신의 시뮬레이션 분석

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(Received 30 August 2018; received in revised form 1 September 2018; accepted 6 September 2018)

ABSTRACT

Flexible track drilling machines are credited with important applications in the area of aircraft manufacturing because of their portability, quick installation capabilities, and high efficiency. However, their structures are special and the constitution principles and motion characteristics are difficult to control, increasing the development costs and research cycle in the context of the technology blockade of foreign companies. The simulation analysis of flexible track drilling machines can be conducted by applying virtual prototypes, shortening the development cycle and reducing the cost. In this paper, a model of a machine is established by using the SolidWorks software and imported into ADAMS to conduct kinematic and dynamic simulation analysis. During the analysis, the feasibility of the configuration is checked, a reasonable driving motion is chosen, potential deficiencies are found, and improvement actions are raised.

Keywords : Flexible Drilling Machine(플렉시블 드릴링머신), Virtual Prototype(가상 프로토타입), ADAMS(아담스), Simulation(시뮬레이션)

1. Introduction

The connections between different segments of the fuselage, fuselage frame and the skin, accessory parts and fuselage are achieved by bolting or riveting. A large number of joint holes have to be manufactured, which is a critical and massive process in aircraft assembly[1]. In traditional aircraft assembly, drilling holes are mainly realized by manual processing, which needs long hours attributed to the various steps and huge quantity. It is also easy to cause defects and demands high artificial technical skills of workers[2-5]. Flexible track drilling machine is one of the mainly

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used portable automation equipment for aircraft assembly. Compared with the five-axis drilling machine, flexible drilling machine has the advantages of light weight, low cost, high automation and so on. So it has been widely used in large aircraft manufacturing companies, such as Boeing and Airbus[6-8]. The traditional design method contains stages of drawing design, physical prototype, testing, and then improvement, which requires a great deal of working time and money. With the development of CAD technique, virtual prototype technology has been valued in the design of equipment and products, especially in the absence of long-term accumulation of technology. It can help designers evaluate the feasibility of design plan without adding too much cost.

In this paper, with the help of virtual prototype technology and simulation software, the kinematic and dynamic characteristics of the flexible drilling equipment were achieved, and then the work of evaluation and modification was carried out to get a reasonable design scheme, providing a reference for the development and application of flexible drilling equipment.

2. Working Principle and 3D Model of Flexible Track Drilling Equipment

The flexible drilling machine was attached to the surface of the fuselage with the help of vacuum chucks. The X-axis motion (parallel to the workpiece surface along the guide rail) was achieved by a mobile car mounted on the rail. The car was mounted on the flexible guide rail by the scroll wheel. The structure of the wheel can adapt to different curvature of the surface, reducing friction in the relative motion of two parts. The movement of the X-axis car along the flexible rail was realized by the electric drive system mounted on the frame of the car. The motion was transmitted through a gear and rack mechanism. The driving gear was connected to the motor shaft and the rack was on the guide rail. Drilling task was completed by the end actuator which was mounted on a Y-axis (perpendicular to the surface to be processed) bracket and driven by the motorized spindle. The Y-direction feed of the end actuator was realized by the roller screw. The Y-direction motion mechanism was mounted on the X-direction mobile car. There was a brake cylinder fit on each of the four scroll wheel distributed on the outside of the guide rails, which can compact the scroll wheel and rails during the drilling operations.

In this paper, the kinematic and dynamic behaviors of the whole system and the rail part were mainly studied. To simplify the model, the end actuator was replaced by a mass block with a certain weight and volume. The three-dimensional (3D) model of the system was established by using the software of SolidWorks as shown in Fig. 1.

3. Preprocessing of Simulation Model

ADAMS(Automatic Dynamic Analysis of Mechanical System) is the most widely used dynamic analysis software[9]. Although the modeling function of ADAMS software is not powerful enough, it has strong data conversion function with other modeling software. So the 3D model of the drilling machine established by using the software of SolidWorks was imported into the ADAMS to build virtual prototype model.

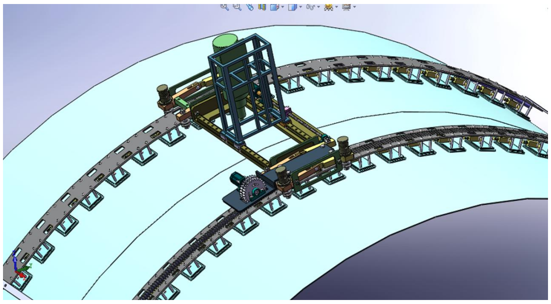


Fig. 1 3D model of flexible track drilling machine

Firstly, the model file in SolidWorks should be saved as a parasolid format (.x_t) file. Then, it was imported into the newly-built model file in ADAMS[10]. After modifying the appearance and material properties of the parts and merging the fixed parts by Boolean operation, each member of the component was connected by kinematic joints. Fixed joints were used between tracks and the ground, gear joint was used between the gear and the right rail, revolute joint was used between the gear and the support, revolute joints were used between the eight connecting rods and the support, revolute joints were established at the center of orbital curvature for the guide wheels mounted on the connecting rods, fixed joint was used between the middle tray and the support. The mass block replacing the end-effector was fixed on the Y bracket, and the translational joint was established between the Y bracket and the X-direction mobile car on the slide rails. Screw joint was established between the mass and the screw rod mounted on the X-direction car. The verification by model simulation shows that there were two degrees of freedom. The post-processing model was shown in Fig. 2.

4. Simulation Analysis of the Kinematics of Flexible Track Drilling Machine Based on ADAMS

4.1 Simulation Conditions and the Driving Speed Functions

Combined with the actual needs, flexible drilling machine should meet the drilling actions as follows: the spacing between the holes was 0.55°, the horizontal distance between each hole was 50mm, and the efficiency of the hole drilling was 5pcs/min. The movement process was set as follows during the simulation： The machine rotated an integer times of 0.55° along the guide track in the first 4s, and then the first hole was drilled in the second 4s, the actuator moved 50mm driven by the screw in the third 4s, the second hole was drilled in the fourth 4s. The above steps were repeated until ten holes finished in recursively. Then the machine moved along the guide rail to the next drilling position, and the actuator was driven in the opposite direction and completed the drilling of ten holes. By now, a drilling cycle was finished within the time of 240s.

Rotation driving was applied on the gear shaft and screw to replace the motor, then the degree of freedom of the model was reduced to zero (DOF=0) and kinematics analysis could be carried out. Depending on the geometry size and kinematic relationships, the gear should turn 20.71°when the machine rotated 0.55° along the track. Three kinds of speed curves which met the condition that the displacement during 0-4s met the above requirements were given. And these speed curves were written as ADAMS function and added to the revolution joint on the gear shaft. The ADAMS functions were written as:

Speed 1:
if(mod(time,120)-2:10.3552/2*mod(time,120),10.3552,
if(mod(time,120)-4:10.3552/2*(4-mod(time,120)),0,0))
*1d

Speed 2:
8.1329*sin(pi/4*time) *if(mod(time,120)-4:1,0,0) *1d

Speed 3:
5.1776*(1-cos(pi/2*time))*if(mod(time,120)-4:1,0,0) *1d

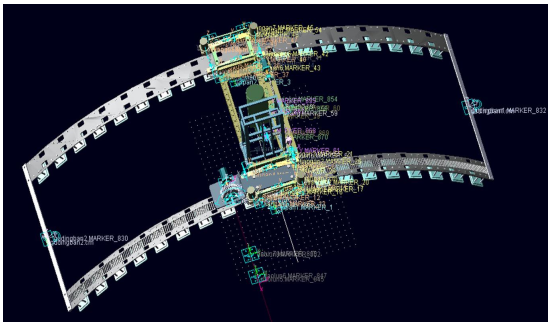
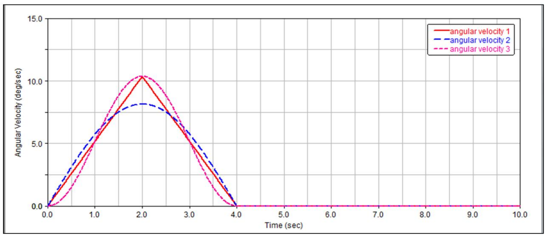


Fig. 2 Flexible track drilling machine model after preprocessing

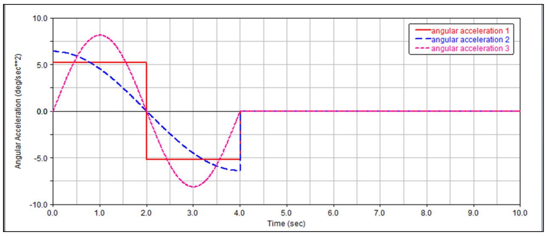
4.2 Simulation Analysis

Firstly, the rotary drive function of the screw was set as 0, the simulation type as kinematic, simulation time as 10s, step size was 1000. Then, measurements of angular velocity and angular acceleration were applied on the rotate pair of the gear shaft. The measurement results were as shown in Fig. 3.

By comparison, there were acceleration mutations in the first and second functions. Sudden changes could be avoided in the third function, which shown the advantages of periodic and infinitely continuous conduction of trigonometric functions in motion control.



(a)



(b)

Fig. 3 Three different kinds of drive angular velocity and acceleration

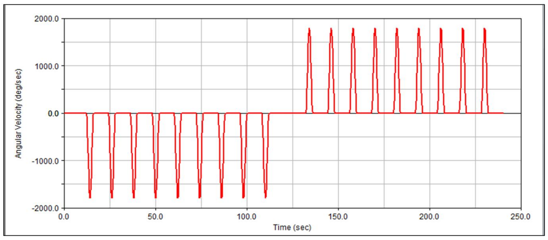


Fig. 4 Drive angular velocity of the screw pair

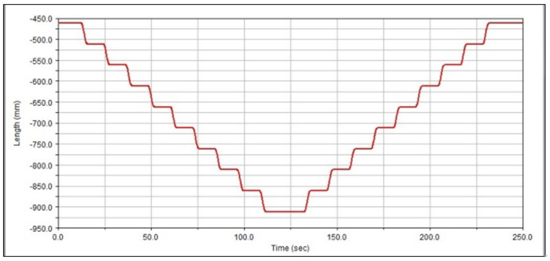


Fig. 5 Y component of displacement

In the same way, the angular velocity driving function of the screw thread pair was given, as shown in Fig. 4. Kinematics simulation was carried out again, setting the simulation type as kinematic, simulation time as 240s and step size as 10000. The displacement curve of the end-effector in Y direction was shown in Fig. 5. It was found from the figure that the machine performed the required drilling operations and avoided the impact during the movement in the given angular speed.

5. Dynamic Simulation Analysis of the Flexible Track Drilling Machine

When the degree of freedom of the system was greater than zero (DOF>0), dynamic analysis, aiming at researching the load conditions between the eight guide wheels and the track and the engaging force of the driving gear assembly, could be conducted.

5.1 Preprocessing of the Simulation Model

For the fuselage diameter was comparatively larger than the drilling equipment in the study, the fuselage was approximately replaced by its outer hexadecagon. That’s to say, the circular arc was replaced by a small straight section at the sixteen specific positions of the fuselage. So that the movement of the guide wheel was simplified as moving in the direction of the linear guide rail, and the guide rail was taken as the rack meshing with the driving gear, as shown in

Fig. 6. Then the linear guide model when the machine was in the bottom of the fuselages was built in SolidWorks and imported into ADAMS, as shown in Fig. 7. Removed the constraints between the eight guide wheels and the track, and solid - solid form contact force was respectively applied[11]. Then speed driving was applied on the gear shaft.

5.2 Simulation Analysis

Set the simulation type as dynamic, simulation time as 5s, and step size as 10000. After the simulation was completed, each contact force could be obtained in the post-processing module.

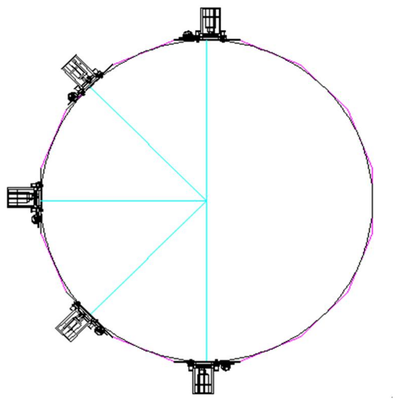


Fig. 6 Simplified schematic diagram of the model

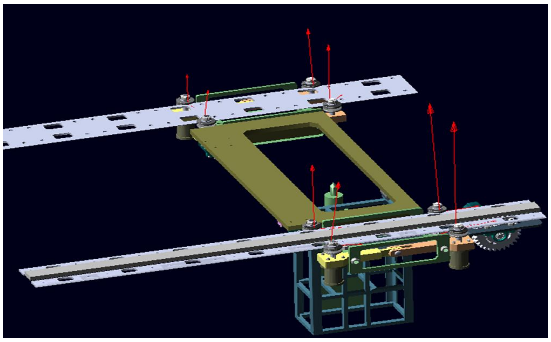
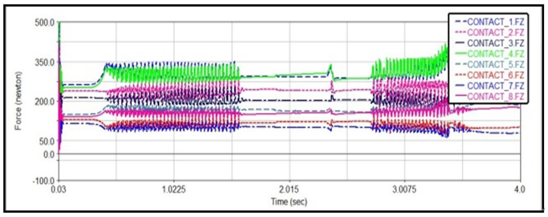
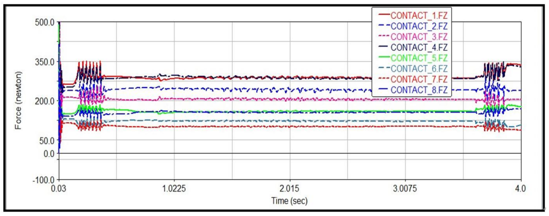


Fig. 7 Drilling machine at the bottom of the fuselage



(a)



(b)

Fig. 8 Z component of contact force

According to the results shown in Fig. 8(a), when the driving speed of the gear shaft during 0-4s was $5.1776(1-\cos(\pi/2t))$ (in degrees per second), the contact forces fluctuated obviously in the first 0.02s because the system was just started to accelerate. There were also large fluctuations during other periods, which must be related to the given velocity amplitude. So the speed function was adjusted and when the speed was 10 times larger, the results were more ideal. The Z components of the 8 contact forces were shown in Fig. 8(b) and the trend of the other components, in X and Y directions were in the similar case. By comparison, when the driving speed was $51.776(1-\cos(\pi/2t))$, the contact forces only fluctuated slightly in a small period near the beginning and ending of the movement.

From the above, increasing the moving speed could improve the working stability. When the driving speed function was selected as $51.776(1-\cos(\pi/2t))$, the drilling machine rotated 5.5°along the guide rail in 4 seconds while the required angle between two drilling stations was 0.55°. So during the actual drilling operation, drilling all the holes of the whole body should be completed in ten times.

Table 1 Component (average) of the contact force (in N)

	Drive Speed 5.1776(1-cos(π/2t))			Drive Speed 51.776(1-cos(π/2t))		
	Fx	Fy	Fz	Fx	Fy	Fz
contact 1	49.03	0.23	306.94	32.73	3.26	289.77
contact 2	48.92	143.38	240.90	29.02	98.80	241.36
contact 3	30.71	1.15	203.47	22.54	-1.02	205.04
contact 4	51.73	-97.79	305.54	34.23	-92.47	288.63
contact 5	28.60	-16.12	169.03	19.34	-2.47	160.20
contact 6	20.04	51.49	113.61	13.32	50.19	120.49
contact 7	10.39	10.08	97.01	8.45	3.70	100.77
contact 8	19.94	-91.95	156.67	15.58	-59.57	154.51
contact 9	-261.73	0	-98.10	-177.24	0	-65.42

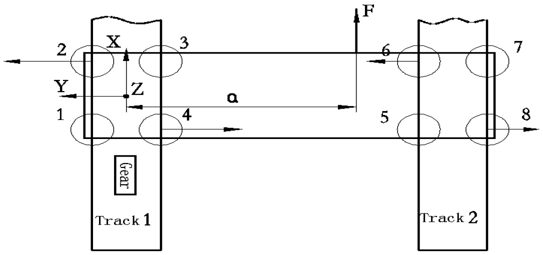


Fig. 9 Simplified schematic diagram of the equipment structure

Table 2 Each component (average) of the contact force (in N)

	1	2	3	4	5	6	7	8
F=0	3.26	98.80	-1.02	-92.47	-2.47	50.19	3.70	-59.57
F=50N	2.57	36.40	-1.28	-34.98	-1.84	24.11	2.48	-27.02
F=60N	3.14	22.44	-1.03	-19.09	-0.47	16.45	2.47	-23.31
F=70N	4.30	7.90	-3.56	-7.28	-0.52	7.24	1.83	-10.06
F=80N	13.39	5.82	-9.07	-7.93	3.80	5.66	-3.87	-7.39
F=90N	24.34	4.30	-17.99	-5.90	8.47	4.74	-10.75	-6.80
F=100N	29.85	2.51	-25.95	-3.64	16.08	3.39	-16.72	-5.10

Table 3 Each component (average) of the gear meshing force (in N)

	Fx	Fy	Fz
F=0N	-237.24	0	-89.42
F=70N	-125.00	0	-46.11
F=80N	-83.25	0	-32.52

That is to say, the machine had to be positioned ten times. Components of the contact forces under the conditions of two different driving speeds were listed in Table 1. When the machine was at the bottom of the fuselage, x axis was parallel to the direction of its movement and Fx represented the friction force, z axis was perpendicular to the top and bottom surface of the guide rail and Fz represented the positive pressure, y direction was perpendicular to the side surface of the track and Fy represented the lateral pressure. It could be found from the statistical results that Fy on contacts 2, 4, 6, and 8 were much larger than those on the other four contacts, and numbering method of the guide wheels (contact number was the same) was shown in Fig. 9.

The reason for the distribution of Fy was that the driving gear meshed with only one of the guide rails leading to the working condition of "one side drags the other" when the system moving forward. Due to inertia, the motion of number 5-8 guide wheels was slower than the other four, which should be avoided in practical work. To resolve these problems, a scheme was proposed: a suitable force F acting along the direction of movement was applied near to the side of track 2 to make the lateral pressure Fy on all the 8 guide wheels was as small as possible and evenly distributed.

According to the structural dimension and simulation results, the force F was applied on the drilling machine with a distance of 900mm from the coordinate origin which was set on the mid line of track 1, as shown in Fig. 9. When the force F was respectively set as 100N, 90N, 80N and 70N, the magnitude of the components Fy (average value within 0-4s) was shown in Table 2.

By comparison, with the increase of force F, Fy of contact 2, 4, 6, and 8 gradually decreased and Fy of contact 1, 3, 5, and 7 gradually increased. When F=50N and 60N, the equilibrium effect was not enough. When F=90N and 100N, the force was too large and played the opposite role. When F=70N and

80N, Fy values of 8 contacts were well distributed. So the magnitude of force F was determined to be 70 to 80N. In addition, when F=70N and 80N, the gear meshing force significantly reduced than compared with when force F was not applied. The size of each component was shown in Table 3.

6. Conclusion

In practical engineering application, it costs a lot of time and funds and needs a long-term experiment and improvement process to develop a set of equipment. With the help of 3d modeling and kinematics and dynamic simulation technology, unreasonable factors in the design can be found and improvement scheme can be proposed, which saves the development expenses and shortens the development cycle. In this paper, the following conclusions were obtained:

1) In order to meet the requirement of drilling, it was necessary to determine the reasonable motion law of the drilling machine.
2) According to the dynamic analysis results of the machine when it works at the bottom of the fuselage, the problem of "one side drags the other" during the movement of the drilling device was found. It was proposed that adding a suitable traction force to eliminate this situation.

Acknowledgement

This study was supported by Basic Science Research Program through the NRF of Korea (NRF) funded by the MEST (NRF-2016R1D1A1A09920105) & many thanks for the help from Zhejiang Shuanghuan Driveline Co., LTD.

References

1. Yuan, H., "Manufacturing Technology of Connecting Hole in Aircraft Structures," Aeronautical Manufacturing Technology, No. 1, pp. 96-97, 2007. (in Chinese)
2. Hong, S. M., Park, D. H., Han, S. G., Song, C. K., "A Study on the Drilling Performance of the Assembly Machine for the an Aircraft's Main Wings", Journal of the Korean Society of Manufacturing Process Engineers, Vol. 17, No. 1, pp. 8~15, 2018.
3. Park, D. S., Jeong, Y. H., "Study on Tool Wear and Cutting Forces by Tool Properties in CFRP Drilling", Journal of the Korean Society of Manufacturing Process Engineers, Vol. 16, No. 4, pp. 83~88, 2017.
4. Yoon, S. H., Cho, S. P., Lyu, S. G., "A Study on Real Time Cutting Monitoring using Profibus", Journal of the Korean Society of Manufacturing Process Engineers, Vol. 15, No. 3, pp. 1~7, 2016.
5. Bo, Y., Xu, G., Xiao, Q., "Precision Technology of Automatically Drilling on the Aircraft," Aeronautical Manufacturing Technology, No. 24, pp. 96-99, 2009. (in Chinese)
6. Guo, E., "Foreign Flexible Assembly Technology of Aircraft," Aeronautical Manufacturing Technology, No. 9, pp. 28-32, 2005. (in Chinese)
7. Jim, B., "Flex Track Drill," SAE Aerofast Conference, 2003. No. 2003-01-2955.
8. Theodore, M., James, N., Buttrick, Jr., Roger, A., "Flexible Track Drilling Machine," Patent, United States. US 6,843,328 B2. Jan. 18, 2005.
9. Li, Z., "Introduction and Examples for ADAMS," National Deference Industrial Press, 2006. (in Chinese)
10. Yu, FP., Jia, H,. "Data Exchange Between ADAMS and CAD Software UG and Solidworks," Machinery Manufacturing Engineer, NO. 10, pp. 37-39, 2015. (in Chinese)
11. Chen, L., Zhang, Y., "Dynamical Analysis of Mechanical System and ADAMS-using course," Tsinghua Publishing House, 2005. (in Chinese)