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Analysis and design study of LCD transfer robot using dynamic simulation and experiment†

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Abstract

Recently, the size of raw glass has been greatly increased in the new generation Liquid Crystal Display (LCD) technology. To handle bigger and heavier glasses, it is necessary to develop a large scale LTR (LCD Transfer Robot) to support various complicated LCD fabrication processes. This adjustment will result in difficult design problems such as vibration, handling accuracy deterioration, and high stress due to heavier dynamic loads. In turn, these will result in inaccurate transfer motion and fatigue cracks.

In this paper, the dynamic simulation technique is introduced to validate a baseline design and to propose new and improved designs for the best performance of heavy-scaled LCD transfer robots. The dynamic models and analysis results were verified by real experiments including strain measure test and motor power test. Using the verified simulation model, some dynamic situations such as the robot's emergency stop and free fall situation, which were not impossible to test using the real proto robot, were analyzed and predicted using the simulation model.

Keywords: Dynamic simulation; Industrial robot; LTR (LCD Transfer robot); Dynamic stress

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1. Introduction

Recently, due to the rapid developments in LCD displays, production cost has been reduced, allowing for the increase in screen size. With the increase in the size of LCD panels, the weight handled by the LCD Transfer Robots has increased and has caused problems. These include problems in handling accuracy and fatigue failure in components. These problems, which are encountered during manufacture, are the main reasons for huge expenditure costs.

If computer aided engineering technology is used during the development of robots to analyze the problems that will arise in the future, problems can be overcome which will reduce the cost and increase product performance and reliability.

In this study, we used flexible multi-body dynamics to analyze the mechanical properties of the 8th Generation (8G) LCD Glass transportation robots. The flexibility in each link, the reducer used in joints, and the compliance of bearings were taken into account to conduct a reliable analysis. Through the simulation of analytical study, we predicted dynamic stress distribution, vibration/handling accuracy, and emergency-stop forces, which are important factors in preventing component failure. The simulation methods used in this study were expected to make controller optimization and fatigue life prediction economical and effective in the future.

2. Introduction of the 8G Link-type LTR

Fig. 1 shows a Link-type LTR used in the transfer of the 8th-Generation LCD Glass (2160mm × 2460

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mm × 0.7mm).

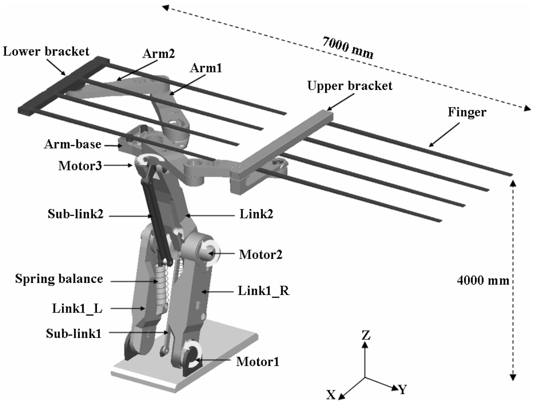


Fig. 1. Heavy-scaled 8G Link-type LTR

The LTR usually has a cylindrical workspace due to its transportation characteristics. To transport two sheets of glass simultaneously, the upper and lower arms are used. Motor3 rotates the Arm-base and Motor4 drives the upper arm in a linear motion.

In the special case of a link-type LTR, a spring balance is fitted between Link1 and Link2 to compensate for Motor2 power, which is responsible for Z-axis movement. For the precision control of handling the glasses, the static deformation at the tip of the finger must be less than 10 mm. Since the joints which connect the arms and links include bearings and reducers, joint compliance must be considered to predict the static deformation at the tip. Flexibilities of the arm itself are also important to both static and dynamic deformation, because the arm is a kind of cantilever type structure with a large lumped mass at the tip. Due to the repetitive motion of robot, the concentration of stress at a certain point is the main cause of fatigue crack of parts.

In this paper, these complex mechanical properties were analyzed and improved using flexible multi-body dynamic analysis technology. In other words, all of the components that make up the robot's link, arm, and hand were modeled into an elastic-body using modal coordinates. Each joint was modeled by stress components instead of mechanical constraint to take into account its characteristics in compliances.

2.1 Modeling of the flexible parts

The major components such as arms and link frames are made of cast iron or cast aluminium. These structural components can be assumed to be linear elastic during normal operation. However, a small elastic deformation may cause vibration and repeated dynamic stresses resulting in inaccurate transfer motion and fatigue cracks. Therefore, it is necessary to establish a methodology for predicting the deformation, vibration, and dynamic stress time histories using the virtual computer simulation model.

Table 1. Component modes for the 8G link-type LTR.

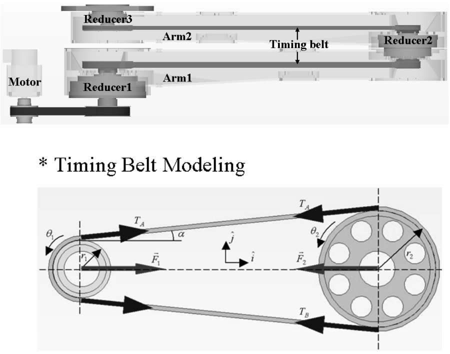
Part Name	Component modes (static + normal)	1st Vibration Mode
Link1_R	24	283.5 Hz
Link1_L	24	240.8 Hz
Link2	42	234.7 Hz
Arm-Base	36	365.2 Hz
Arm1	18	378.7 Hz
Arm2	18	295.4 Hz
Sub-link1	18	72.2 Hz
Sub-link2	18	72.2 Hz
Lower-Bracket	36	117.5 Hz
Upper-Bracket	36	49.5 Hz
Finger	12	38.6 Hz

Link-type LTR's elastic multi-body dynamics model is composed of 22 flexible bodies and 25 rigid bodies which gives it 495 degrees of freedom.

The component mode synthesis technique [1-3] can be used for efficient computer simulation in a large rigid body gross motion with small elastic deformation. Since the component mode synthesis method employs modal coordinates to consider the elastic deformation of the flexible bodies, it is possible to more effectively execute the large multi-body dynamic system analysis using the small number of well-selected modes. Table 1 shows the number of component modes and its first vibration modes that were used for flexible multi-body dynamics.

2.2 Modeling of arm mechanism

For parallel rectilinear motion of the finger and bracket, a timing belt at each arm system is modeled to drive at a constant speed ratio. As shown in Fig. 2, to represent the elasticity and damping of the belt, spring and damping forces are approximated to be proportional to the displacement and velocity of the belt length change. Also, the structure of the reducer connecting the arms was designed to transfer the motor-torque efficiently. In addition, the reducers are modeled using dynamic force elements. In other words, the joint compliances for reducers are modeled



$$T_A = T_0 + k(r_1\theta_1 - r_2\theta_2) + k(r_1\dot{\theta}_1 - r_2\dot{\theta}_2)$$
$$T_B = T_0 - k(r_1\theta_1 - r_2\theta_2) - k(r_1\dot{\theta}_1 - r_2\dot{\theta}_2)$$
$$M_1 = -r_1(T_A - T_B) - f_1(\dot{\theta}_1)_{Nonlinear\ Friction}$$
$$M_2 = r_2(T_A - T_B) + f_2(\dot{\theta}_2)_{Nonlinear\ Friction}$$

Fig. 2. Dynamic modeling of arm system.

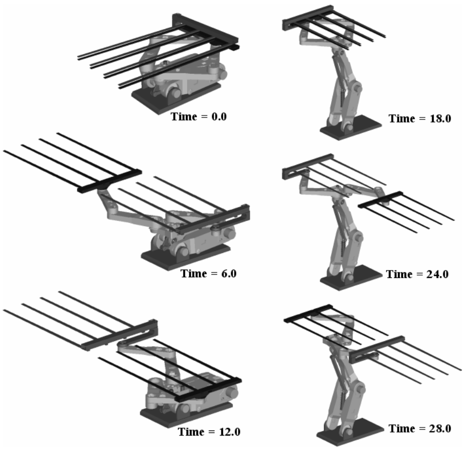


Fig. 3. Simulation of link-type LTR.

in a similar way with spring and damper elements.

3. Dynamic analysis and experiment

Fig. 3 shows the robot simulation during the transfer of the LCD Glass.

In Fig. 4, the magnitude of torque working on Motor3 was compared between the prototype test and simulation. The result shows that they are very consistent with each other.

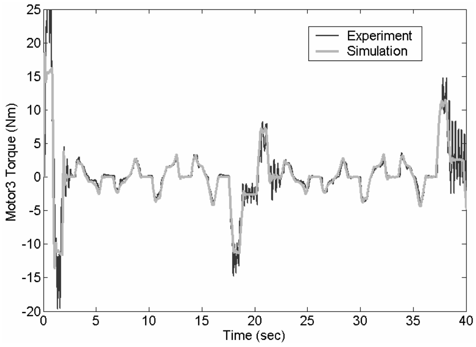


Fig. 4. Torque measure and analysis result of Motor3.

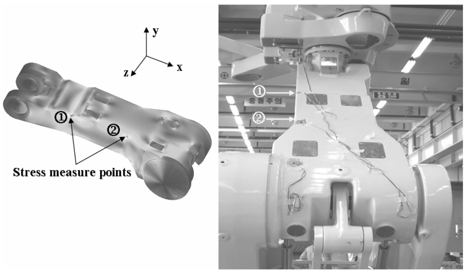


Fig. 5. Stress measure experiment.

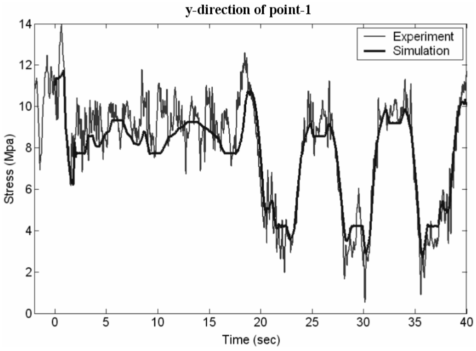


Fig. 6. Dynamic stress time history on Zlink2.

To predict the mechanical fatigue of elastic parts, the dynamic stress was calculated from the flexible multi-body analysis. To validate the accuracy of the stress analysis result, the actual prototype test was executed using the rectangular rosette gauge. In the experiment, strain gauges were attached where stress was predicted to be greatest during simulation. In Fig. 5, Zlink2 is shown with the strain gauge attached at predicted stress points.

In Fig. 6, the predicted stress levels from simulation and actual stress levels in prototype are shown.

4. Design study using dynamic simulation

The verified simulation model can be used to estimate and improve the design result of the LTR.

Fig. 7 shows the vertical deflection at the finger-end during the linear motion of the upper finger. This information is very important in the compensation of

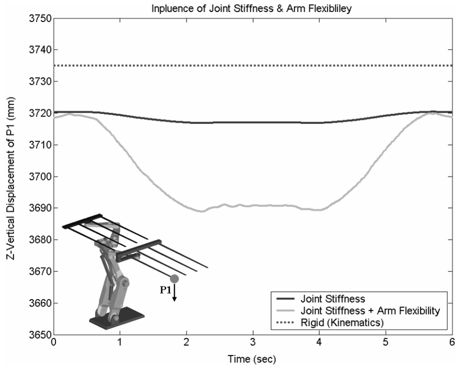


Fig. 7. Estimation of vertical transfer accuracy.

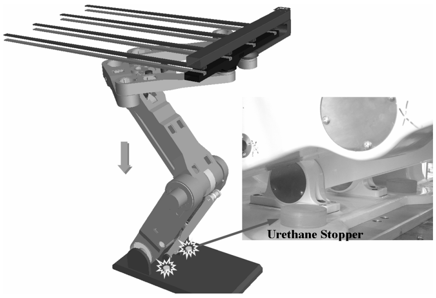


Fig. 8. Simulation model for free falling.

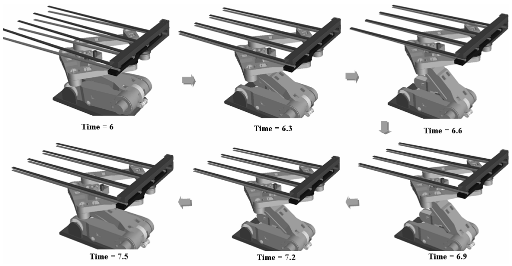


Fig. 9. Free falling simulation.

the vertical transfer accuracy of the LCD glass. In other words, the vertical deflection of less than 10 mm can be achieved by more studies using simulation result and optimum design [4].

The verified simulation model can be efficiently utilized for predicting a robot's dynamic characteristics during a collision, emergency stop, or free fall. These types of predictions are especially necessary for the robot's safety and reliability. In this study, the robot's behavior was analyzed during the simulated vertical (Z-axis) free fall. In reality, a robot weighing over 2 tons would be seriously damaged in such a circumstance.

Fig. 8 illustrates the collision area when the robot free falls. The collision area of the robot is covered with a urethane-block, as in the prototype. The collision of simulation model's Link1 and urethane-block was modeled using solid-solid contact properties. Freefall simulation is shown in Fig. 9. The highest stress level was at Link1-R and the value was next to the yield stress of the aluminum casting material. This means serious damage when in actual conditions.

5. Conclusion

A simulation model was created for the heavy-scaled robot's dynamic analysis and design improvement. Using this simulation model, the robot's dynamic stress related to the component's fatigue life was predicted and this data was verified via real testing with a prototype. Furthermore, using the verified simulation model, we predicted the vertical deflection related to transfer accuracy and the effect on the robot during erratic circumstances that would create a free fall situation.

This study will be continued towards optimization of the robot's controller and finding the methods that can predict the component's fatigue life in economical and effective ways.

References

[1] A. A. Shabana, *Dynamics of Multibody Systems* 2nd Edition, Cambridge University Press, (1998).

[2] S. S. Kim and E. J. Haug, Selection of Deformation Modes for Flexible Multibody Dynamics. Mechanics of Structures and machines. 18 (4) (1990) 565-586.

[3] J. H. Ryu, H. Kim, H. J. Yim, An Efficient and Accurate Dynamic Stress Computation by Flexible Multibody Dynamic System Simulation and Reanalysis, Journal of Mechanical Science and Technology, 11 (4) (1997) 386-396.

[4] J.-C. Hwang, J.-H. Seo and Y.-W. Choi, Error Compensation of a Large Scale LCD Glass Transfer Robot, Proceedings of International Federation of Automatic Control, No.TuC18.5, July 6-11, Seoul, Korea, 2008.

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