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题　　目：Dynamic load analysis and Design methodology of LCD transfer robot

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Dynamic load analysis and design methodology of LCD transfer robot

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Abstract

The objective of the present study is to develop a design methodology for the large scale heavy duty robot to meet the design requirements of vibration and stress levels in structural components resulting from exposure of system modules to LCD (Liquid Crystal Display) processing environments. Vibrations of the component structures significantly influence the motion accuracy and fatigue damage. To analyze and design a heavy duty robot for LCD transfer, FE and multi-body dynamic simulation techniques have been used. The links of a robot are modeled as flexible bodies using modal coordinates. Nonlinear mechanical properties such as friction, compliance of reducers and bearings were considered in the flexible multi-body dynamics model. Various design proposals are investigated to improve structural design performances by using the dynamic simulation model. Design sensitivity analyses with respect to vibration and stresses are carried out to search an optimal design. An example of an 8G (8th-Generation) LTR (LCD Transfer Robot) is illustrated to demonstrate the proposed methodology. Finally, the results are verified by real experiments including vibration testing.

***Keywords*:** Flexible multibody dynamics; LTR (LCD Transfer Robot); Vibration fatigue

1. Introduction

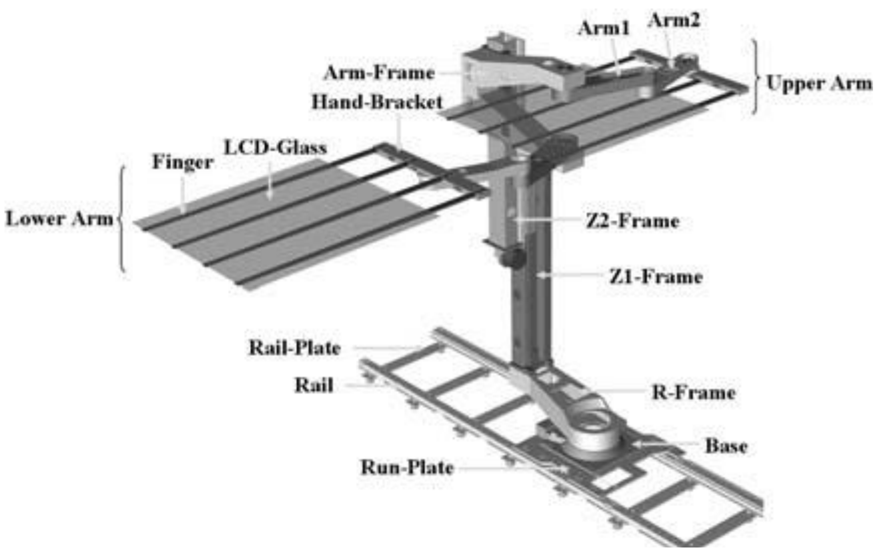
LCDs are widely used in TV's, computers, mobile phones, etc., because they offer some real advantages over other display technologies. They are thinner and lighter and draw much less power. Recently, the size of raw glass has greatly increased in new generation LCD (Liquid Crystal Display) technology. In order 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.It will cause many difficult design problems such as vibration, handling accuracy deterioration and high stresses due to heavier dynamic loads, resulting in inaccurate transfer motion and fatigue cracks. Therefore, it is necessary to establish a methodology for predicting deflections, vibrations, and dynamic stress time histories using virtual computer simulation models. An integrated design simulation method would be useful to validate a baseline design and to propose new improved designs. In this paper an integrated computer simulation methodology is presented to predict deflections, dynamic stresses due to vibrations design, based on the existing FEM and flexible body dynamics technology.

The proposed methodology is applied to the LTR that handles 7G/8G LCD glasses. Vibration analysis is performed and validated with the vibration modal test to identify and to recapture the inherent phenomenon in the system. Some flexible components in the LTR may experience severe vibration to cause fatigue damage due to large dynamic loads. Modal characteristics are used to consider structural flexibility in flexible multi-body dynamic simulations. Tip deflection of the end-effecter can be calculated to see if design requirements are met. Dynamic loads and dynamic stress histories can be obtained from the dynamic simulation. Stress levels are investigated at the critical areas to predict if fatigue cracks might occur. If the stress level is not in a safe region, design change should be made based on the computer simulation results and design sensitivity study. Then a prototype LTR is built and tested for design validation.The present paper describes the CAE-based durability analysis that is being implemented and developed at SAMSUNG, to predict fatigue damage corresponding to durability tests. The proposed methodology can be used to develop a new large scale LTR robot in the early design stage.

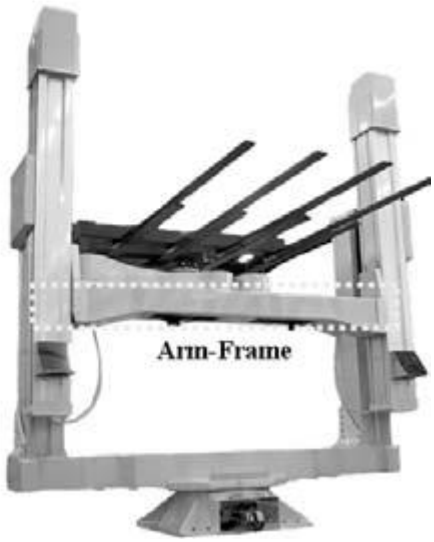
2. Introduction of LCD-transfer robot

Fig. 1 shows various types of LTRs. Telescope type LTR consists of a base frame, an R-frame, two Z-frames, two articulated arms with slender hands as shown in Fig. 1(a). The frame structures are fabricated with cast iron and aluminium. Hands with slender fingers are made of lightweight composite materials.It also has two arms (upper and lower arms) to handle two glasses simultaneously. The LTR has a cylindrical workspace to transfer glasses for various fabrication processes. For precision control of handling the glasses, 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.

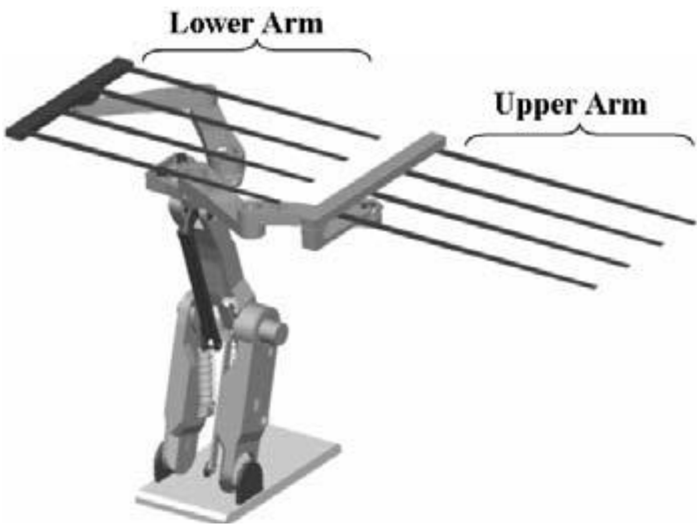
LTR is supposed to repeat millions of cycles to perform LCD fabrication processes in real life. Therefore, it has to pass physical tests to ensure the survivability of the robot system when subjected to static and cyclic loadings. The durability test involves a cyclic loading apparatus that evaluates the durability characteristics of the component structure. Among the many different tests, one of the most critical is the hand motion of stretching out and pulling in with the zframe's vertical motion. The critical motion simulates the jerking and twisting impact that an arm support bracket might experience when running with large glasses loaded. The arms and hands are synchronized and moved at a speed of about 4 m/s.



(a) Telescopic type



(b) Gate type



(c) Link type

Fig. 1. LCD Transfer robots (LTR).

Since the LTR repeats millions of cycles of particular loading and unloading with various configurations,it may result in fatigue failure at a critical stress area.In this paper, to predict static and dynamic deformation at the tip of the finger and critical stress levels including vibration of the LTR, flexible multi-body dynamic simulations are presented. Link-frames,arms are modelled as flexible bodies. Static and dynamic deformation is assumed to be very small, therefore,within the linear elastic range. To represent the flexibility, vibration normal modes and static correction modes are obtained from the finite element vibration and static analysis for each flexible component.To represent the joint compliance, spring and damper force elements are used instead of kinematic joint elements [1].

3. Flexible multi-body dynamics

The main advantage of using modal coordinates in flexible multi-body dynamics is the reduction in the number of generalized coordinates that must be included in the analysis. Two types of modes are used in component mode synthesis for flexible multi-body dynamics [1, 2]. One is a normal mode. The other is a static mode. All used normal modes and static modes must be normalized to have the same magnitude and be orthogonalized to be independent to each other.

3.1 Kinematics of flexible components

A typical flexible component is shown in Fig. 2. The flexible component *i* is discretized into a large number of finite elements. The global position of a point *p* in a flexible part *i* can be represented as

$$\mathbf{r}_p^i = \mathbf{R}^i + \mathbf{A}^i\bar{\mathbf{u}}^i = \mathbf{R}^i + \mathbf{A}^i(\bar{\mathbf{u}}_o^i + \bar{\mathbf{u}}_f^i) \qquad (1)$$

Where $\mathbf{R}^i$ is the global position vector of the X'-Y'-Z' body reference frame, $\mathbf{A}^i$ is the coordinate transformation matrix from the body reference frame to the global inertial frame, $\bar{\mathbf{u}}_o^i$ is the initial position vector of the point p from the body reference frame, and $\bar{\mathbf{u}}_f^i$ is the displacement vector due to deformation.The displacement vector $\bar{\mathbf{u}}_f^i$ can be approximated by a linear combination of deformation modes like Eq. (2).

$$\bar{\mathbf{u}}_f^i = \mathbf{\Psi}^i\mathbf{\eta}^i = \sum_{j=1}^{M}\psi_j\eta_j \qquad (2)$$

Where $\mathbf{\Psi}^i = \mathbf{\Psi}^i(x^i, y^i, z^i) = [\mathbf{\Psi}_t^i, \mathbf{\Psi}_r^i]$ is a modal matrix and ψ_j is the corresponding deformation mode of a flexible part i. $\mathbf{\eta}^i = \mathbf{\eta}^i(t)$ is a 6N□1 modalvector and η_j is modal coordinates, M is the number of modal coordinates. The deformation modes can be normal modes, static modes, or combination of normal and static modes. Used M modes should be linearly independent to each other.

3.2 Flexible multi-body dynamic equations

As shown in Fig. 2, the nodal position vector of a typical point *p* in the global reference frame can thus be written as Eq. (3) by using Eq. (2)

$$\mathbf{r}_p^i = \mathbf{R}^i + \mathbf{A}^i\bar{\mathbf{u}}^i = \mathbf{R}^i + \mathbf{A}^i(\bar{\mathbf{u}}_o^i + \mathbf{\Psi}_t^i\,\mathbf{\eta}^i)$$
$$\mathbf{\pi}_p^i = \mathbf{\pi}^i + \mathbf{\Psi}_r^i\,\mathbf{\eta}^i \qquad (3)$$

Where $\bar{\mathbf{u}}^i = \bar{\mathbf{u}}_o^i + \mathbf{\Psi}_t^i\,\mathbf{\eta}^i$ and the rotational displacement*i* $\mathbf{\pi}_p^i$ of nodal point *p* is defined by $\mathbf{\Psi}_r^i\,\hat{\mathbf{\eta}}^i$. The combined set of kinematic and driving constraints of the multi-body dynamic system may be written in the form [3, 4]

$$\mathbf{\Phi}(\mathbf{q}, \mathbf{t}) = \mathbf{0} \qquad (4)$$

Where the generalized coordinates $\mathbf{q} = [\mathbf{q}_r^T, \mathbf{q}_f^T]^T = [\mathbf{r}^T, \boldsymbol{\pi}^T, \boldsymbol{\eta}^T]^T$, $\mathbf{t}$ is the time, $\mathbf{\Phi}$ is the constraint equation. Using the Lagrange Multiplier Theorem, variational equations of motion of the multi-body system may be obtained by summing all bodies and constraints in the system as in the matrix form of Eq.

$$\begin{bmatrix} \mathbf{M}^* & \mathbf{\Phi}_\mathbf{q}^T \\ \mathbf{\Phi}_\mathbf{q} & \mathbf{0} \end{bmatrix} \begin{bmatrix} \ddot{\mathbf{q}} \\ \boldsymbol{\lambda} \end{bmatrix} = \begin{bmatrix} \mathbf{Q}^* \\ \boldsymbol{\gamma} \end{bmatrix} \qquad (5)$$

This is a mixed system of differential-algebraic equations of motion for considering the elastic effect of the mechanical system. To solve mixed differential algebraic equations, many numerical algorithms have been developed [3]. Using Eq. (5), dynamic stress history of a flexible component can be calculated [5].

4. Dynamic modelling of an lcd-transfer robot

The 8G-Telescopic type LTR system shown in Fig.

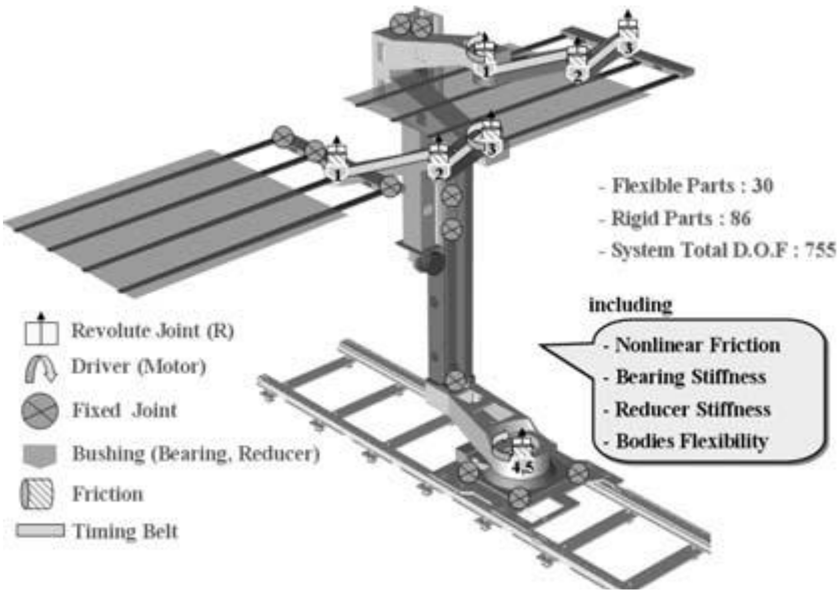
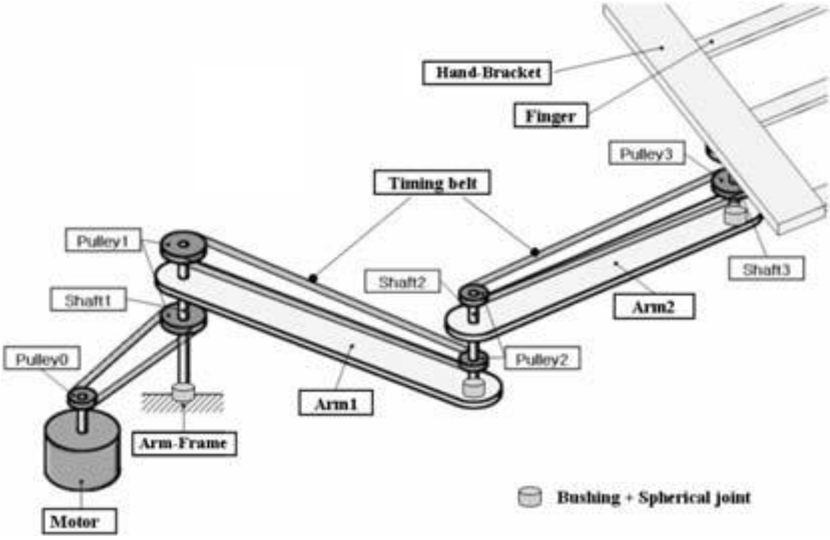
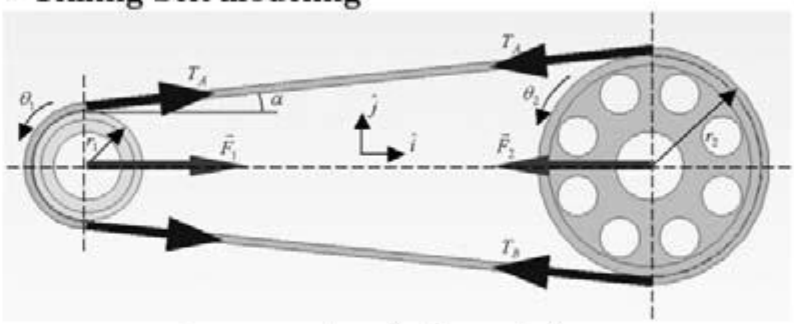


Fig. 3. Flexible multi-body dynamics model for 8G-Telescopic

LTR.



*** Timing belt modeling**



$$T_A = T_0 + k(r_1\theta_1 - r_2\theta_2) + c(r_1\dot{\theta}_1 - r_2\dot{\theta}_2)$$

$$T_B = T_0 - k(r_1\theta_1 - r_2\theta_2) - k(r_1\dot{\theta}_1 - r_2\dot{\theta}_2)$$

$$M_1 = -r_1(T_A - T_B) - f_1(\dot{\theta}_1)_{Nonlinear\ Friction}$$

$$M_2 = r_2(T_A - T_B) + f_2(\dot{\theta}_2)_{Nonlinear\ Friction}$$

Fig. 4. Dynamic modeling of LTR arm system

1(a) can be modeled with 86 rigid bodies, 30 flexible bodies, kinematic joints, and force elements [3]. The flexible bodies considered in the multi-body dynamic simulation are named in the Fig. 1(a). Fig. 3 shows the flexible multi-body simulation model for 8GTelescopic LTR.

For parallel rectilinear motion of the finger and hand-bracket, a timing belt at each arm system is modeled to drive at constant speed ratio. As shown in Fig. 4, to represent the elasticity and damping of the belt, spring and damping forces are approximated to be proportional to displacement and velocity of the belt length change. Even the joint compliances for bearing and reducers are modeled in a similar way with rotational-spring and damper elements. The experimental values from the components' makers are shown in Table

1.

Major components such as arms and link frames are made of cast iron or cast aluminium. Those structural components can be assumed to be linear elastic during normal operation. However, such 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 with a virtual computer simulation model.

Component mode synthesis technique [1-4], explained in the previous section, can be used for efficient computer simulation in large rigid body gross motion with small elastic deformation. Since the component mode synthesis method employs modal coordinates to consider the elastic deformation of flexible bodies, it is possible to execute a large multibody dynamic system analysis more effectively by using a small number of well-selected modes.

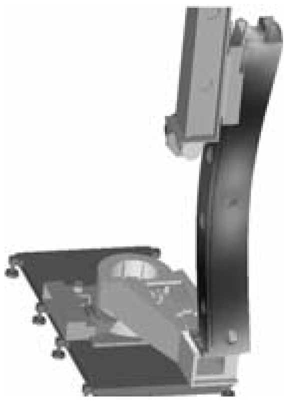
Fig. 5 shows the 1st vibration modes of flexible components in the telescopic LTR in Fig. 1(a). Also,Fig. 5 shows a typical component mode and the number of modes used in the mode component synthesis method for the flexible multi-body dynamic analysis.

Table 1. Joint stiffness for bearing and reducers.

No	Axial	Stiffness Radial	Stiffness Part
1	180 KNm/rad	2570 KNm/rad	Reducer
2	250 KNm/rad	3510 KNm/rad	Reducer
3	67 KNm/rad	1000 KNm/rad	Reducer
4	6745 KNm/rad	43840 KNm/rad	Reducer
5	0	436360 KNm/rad	Bearing

(a) Finger (36)

(c) Arm-Frame (42)



(d)

Z1-Frame (24)


(e) Z2-Frame (24)


(f) R-Frame (36)

Fig. 5. Component modes of flexible bodies (number of modes used for dynamic simulation).

5. Analysis and design improvement of LTR

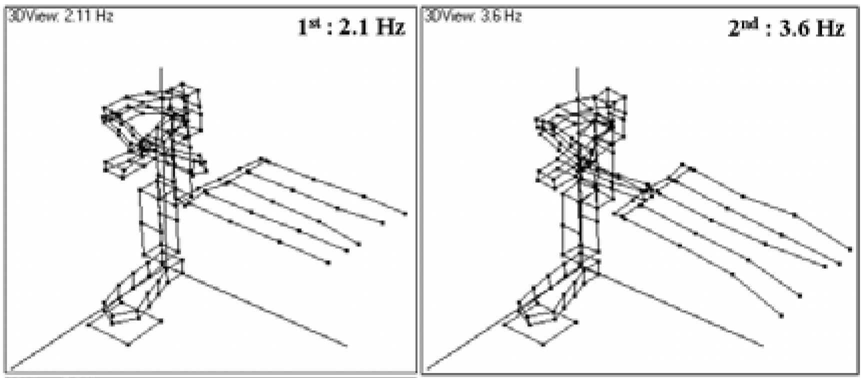
5.1. Modal analysis of 8G-telescopic LTR

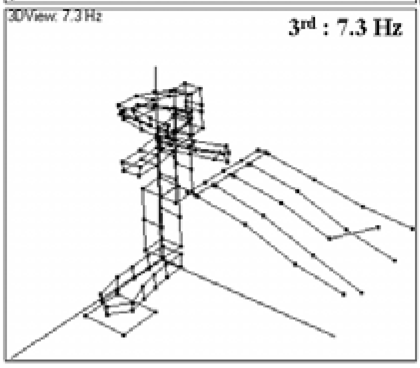
Since major structural bodies such as arms and link-frames are modelled as flexible bodies, the proper kinematic joints and force elements, fundamental vibration modes of the total LTR system can be investigated. The modes calculated from the vibration analysis can be used for searching for the structural weak point and used for the flexible multi-body dynamic simulation explained in the previous chapter. Fig. 6 shows the modal deformation from the vibration test of the LTR system. Analytical vibration modes calculated from the dynamic simulation model are compared with the experimental test results for validation. Comparison with the modal test results showed that simulation results correlate well with the test results. From the results of the analytical and experimental modal deformation, we found that the structural weak point was the R-frame. This information was very important to reduce the system vibration,as explained in the following section.

5.2 Vibration analysis and design improvement

Design problems such as tip deflection and fatigue crack can be investigated with a valid simulation model. Among the various process events for LCD glass transfer motion, stretching out and pulling in motions of the hands with glass loaded are the most critical motions to cause severe vibration and high stresses at the supporting bracket structure. Using the proposed flexible multi-body simulation technology, the critical motion is regenerated to investigate how large deflection and stresses occur during the operation. Since we have a valid simulation model, we can investigate various design proposals.After the prototype robot was developed, undesirable vibration at the measure point was observed when the robot was running onto the guide rail, as shown in Fig. 7. The cause of the vibration was the insufficient stiffness of the R-frame, studying from the analysis of the system modal deformation, as explained in the previous section. In other words, the Rframe at the base of the LTR was known to be a critical component for the vibration.

To increase bending and twisting stiffness, height and width of the beam cross section was enlarged,and ribs were added as explained in the Fig. 7. Even aluminium material is replaced with high strength steel to increase the elastic modulus. To verify the design modification, a dynamic simulation model was used.





Mode No.	Experiment	Simulation
1	2.1 Hz	2.4 Hz
2	3.6 Hz	3.5 Hz
3	7.3 Hz	7.2 Hz
4	11.6 Hz	10.9 Hz

Fig. 6. Vibration modes by experiment and comparison of frequencies

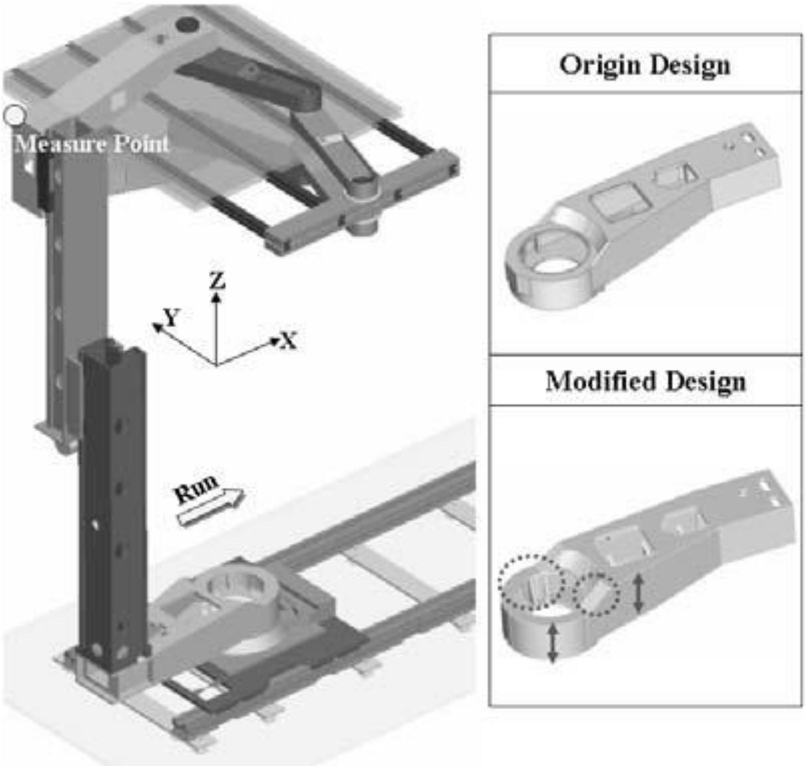


Fig. 7. Design study to reduce the vibration by dynamics simulation.

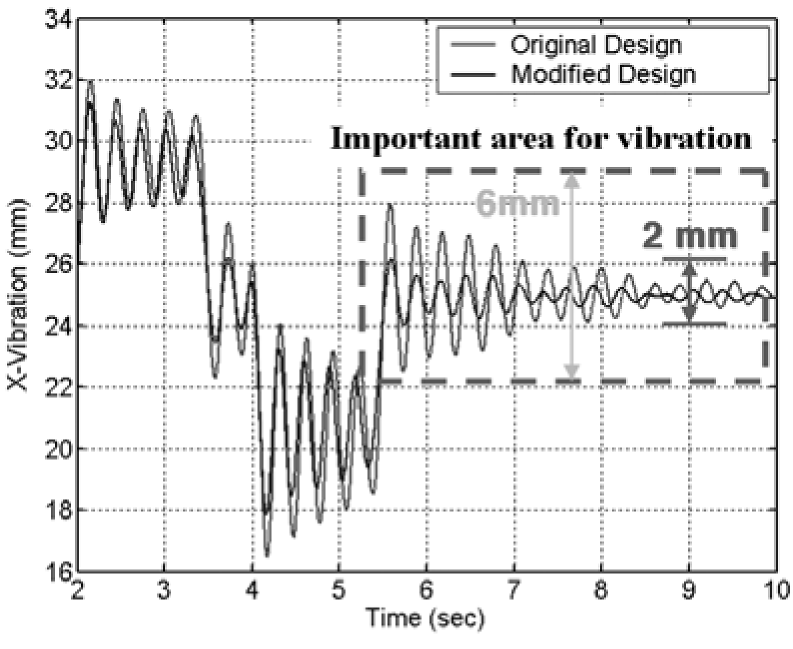


Fig. 8. Comparison of vibration levels between the original and modified design.

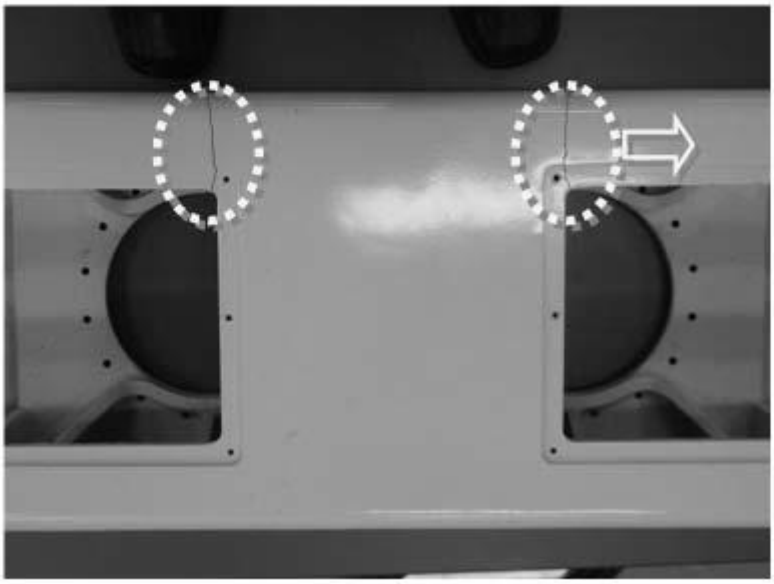


Fig. 9. An example of the crack fatigue.

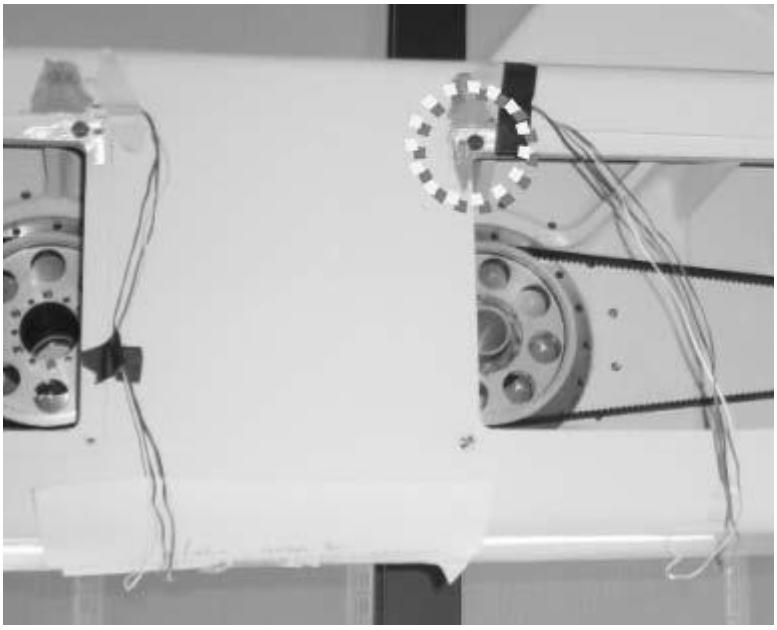
Fig. 8 shows a comparison of vibration displacements during the simulated motions between the original baseline design and the new improved design. More than 50% reduction of the vibration level is observed during the critical motion period from 5 to 10 seconds even at the prototype test as shown in Fig. 8.

5.3 Stress analysis and design improvement

As the size of raw glass tends to become larger for productivity and manufacturing cost competitiveness,LTR robots need to be faster and bigger to handle the larger and heavier glasses with higher speed. This may result in increased dynamic loads causing fatigue cracks due to dynamic stresses.

Fig. 9 shows an example of the fatigue cracks due to dynamic loads at the supporting arm-frame structure in the 7G-Gate LTR shown in Fig. 1(b). Using the flexible multi-body dynamic simulation, cause and effect for the fatigue crack can be analyzed prior to adoption in an actual spot. To reduce the level of dynamic stress at the critical area, the shape and thickness of the structure must be redesigned based on the validated simulation model. Experimental tests were executed to validate the accuracy of dynamic stresses predicted in virtual computer simulations, as shown in Fig. 10. And the result was exactly the same as the point of occurrence of the crack. Fig. 11 shows the design modification. To reduce the stress concentration, the rectangular shape with sharp corners was changed to a round shape, and ribs were changed.

Fig. 12 shows a comparison of maximum dynamic stresses between the modified shape and original shape with different metal thickness. The stress measure point of the part is the dotted circle area in the Fig. 10. This result shows the conclusion that the design was reasonably modified. Practically, the modified design was adopted for the 7G-Gate LTR in the actual spot.



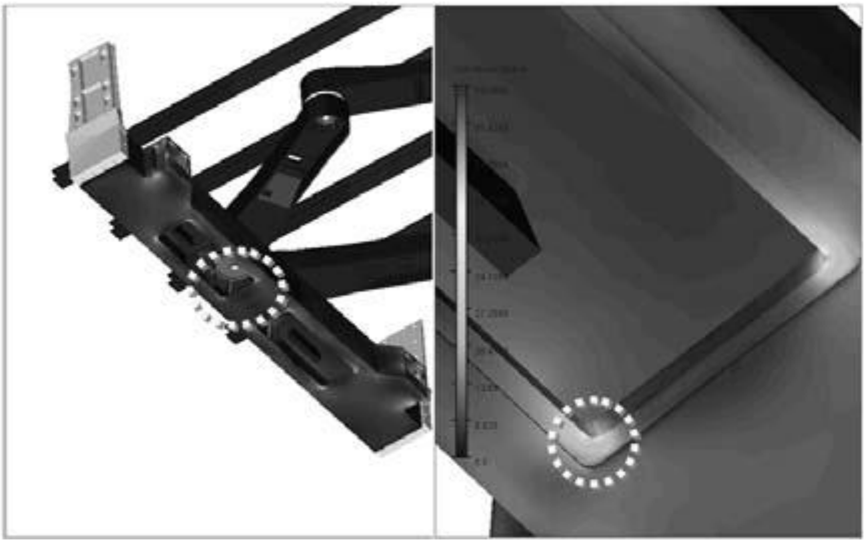


Fig. 10. Strain experiment and dynamic analysis for fatigue life prediction.

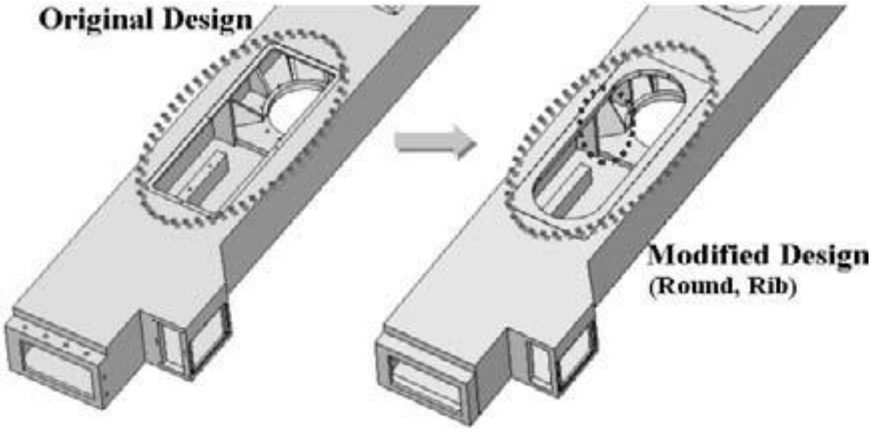


Fig. 11. Design modification for avoiding stress concentration.

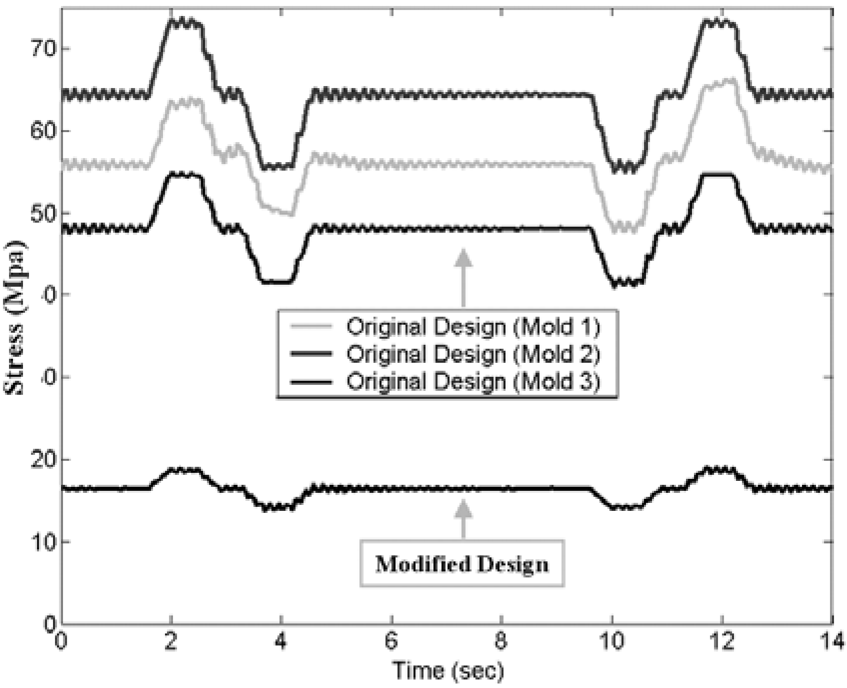


Fig. 12. Stress analysis and design improvement

5.4 Handling accuracy and design optimization

If dynamic loads are increased, it might deteriorate the accuracy of the precision transfer motion due to deflection and deformation of major structural components [6]. Fig. 13 shows the vertical deflections at the tip points of the fingers for the baseline design of the 8G-Telecscopic LTR.The tip deflection of the original design of the LTR was 42 mm. This exceeds the design specification requirement of 10 mm for the LCD fabrication process, and may be the cause of the collision between cassette and robot hands. The cause of the deflection was that the robot structure was very large and heavy. As a result, the deflection must be reduced and the transfer accuracy improved by using the dynamic simulation and optimized design techniques. To reduce the dynamic deflection, a thin-tapered circular plate, what we called a liner, was used, as shown in Fig. 14.

The combination of the three liners’ thickness is very important to reduce the deflection and to optimize the transfer accuracy. So we used dynamic simulations and D.O.E (Design of experiment) for optimization. Fig. 15 shows the proposed simulation methodology which can be used to minimize the deflection at the tip of the finger.

The object function was minimization of the differences of the vertical z-displacement of 4-points in Fig.13. The used D.O.E table was a central composite design table with 3-levels and 3-factors [7]. Table 2 shows the regression analysis result (ANOVA table).

Through the response surface model calculated from the regression analysis [7], the optimized liner thickness was t1=0.50, t2=0.48, t3=0.78 mm. The simulation results for the optimized variable (liner thickness) are shown in Fig. 16. The deflection was reduced only to 5.8 mm. But 42 mm deflection occurred in the baseline design as shown in Fig. 13.

An experimental test using the laser tracker was carried out to validate the optimized simulation result.As shown in Fig. 17, the experimental result was about 6.1mm.

The simulation results of dynamic deflection were very similar to the test results. This means that we reinforced the structural stiffness without any additional expense.

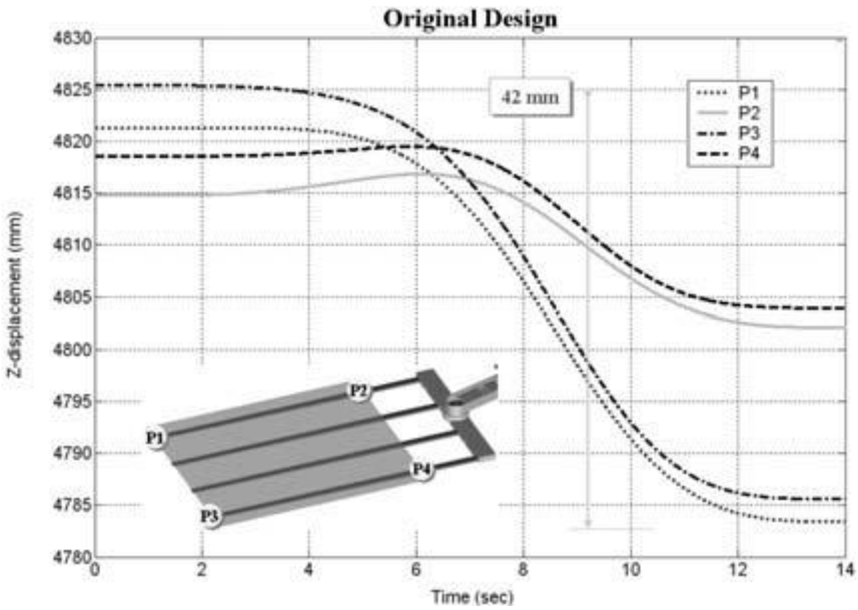


Fig. 13. Vertical deflection of the fingers for baseline design

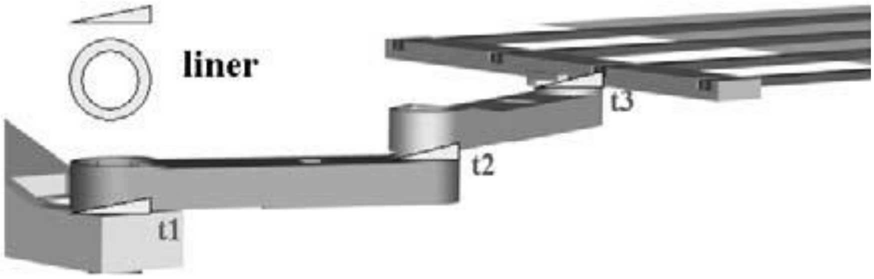


Fig. 14. Robot arm and liner (thin circular plate).

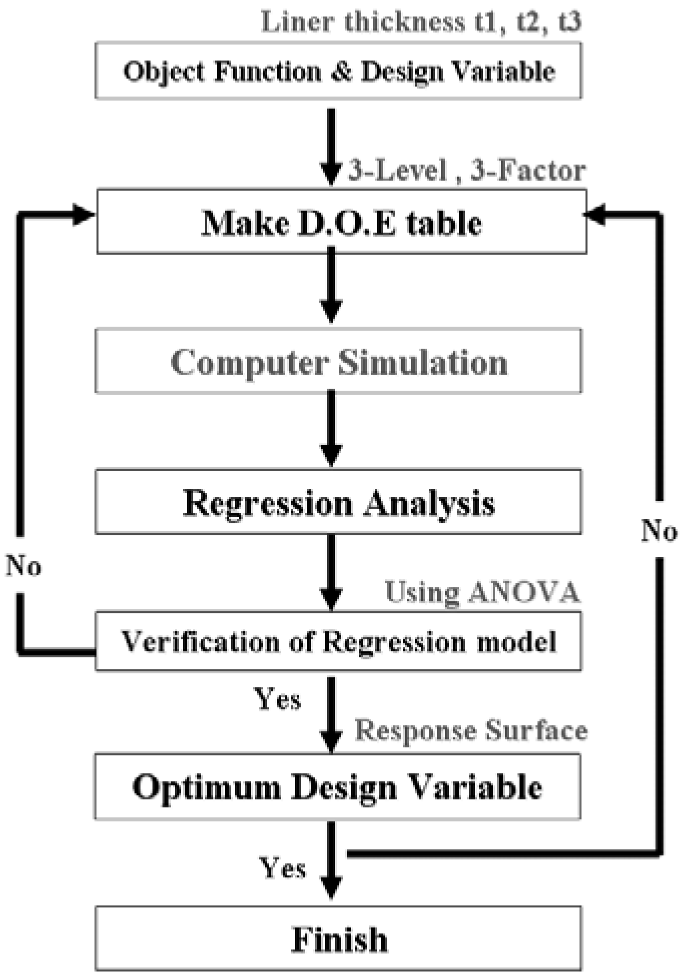


Fig. 15. Process for design variable optimization.

Table 2. ANOVA table for optimization.

Factor	S	V	F_0	$F(\sigma)$	P
Regression	175.085 (SSR)	58.362 (MSR)	145.49	22.04	0.002
Residual	4.412 (SSE)	0.401 (MSE)	Coefficient of Determination $R^2 = 97.54\,\%$		
Sum	179.498 (SST)				

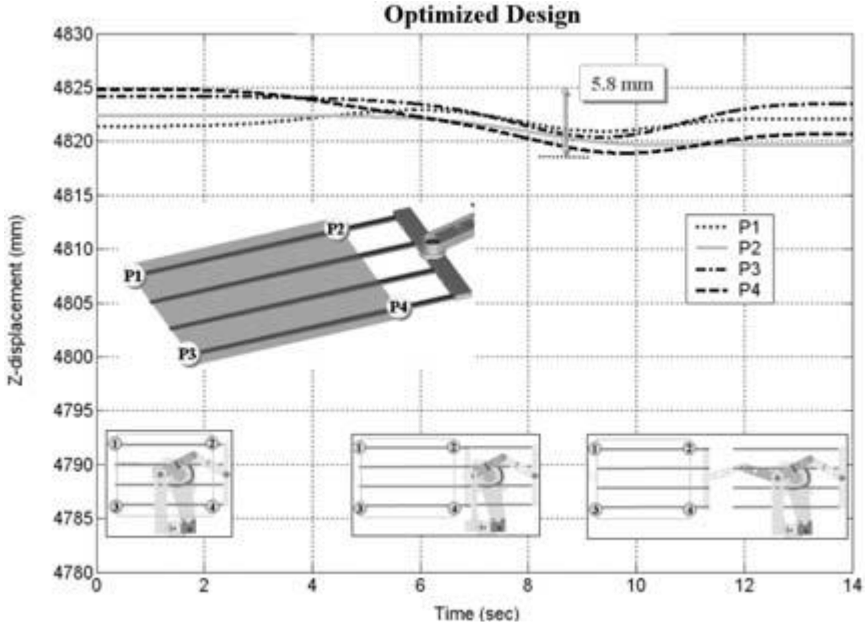


Fig. 16. Optimized design result using dynamic simulation and D.O.E.

6. Conclusions

A computer simulation methodology was presented for vibration and fatigue analysis of the LTR system.Variable amplitude multi-axial loading conditions can be generated to investigate any structural deflection, vibration, and dynamic stress. Flexible bodies were modelled by using component mode synthesis technique.To represent joint compliance and belt flexibility,spring and damper force elements were introduced with proper approximation. To have a validsimulation model, vibration modes of the total LTR system were compared with the modal test results.Comparison of the analysis and test results shows that they correlate well with each other. Deflection of the tip of the end-effector was investigated with the proposed methodology. To reduce the tip defection, a better design can be developed with the simulation model. Fatigue crack failure related to the dynamic stress can be predicted with the baseline design. To prevent fatigue failure at a critical area, stresses were reduced by changing the structural design. The results of the virtual durability assessment were quite good,and showed good correlation with the areas of failure Fig. 17. on the test. The value of being able to predict service lives based on results obtained exclusively in the virtual domain is obvious. The proposed methodology can be used to develop another type of LTR system.

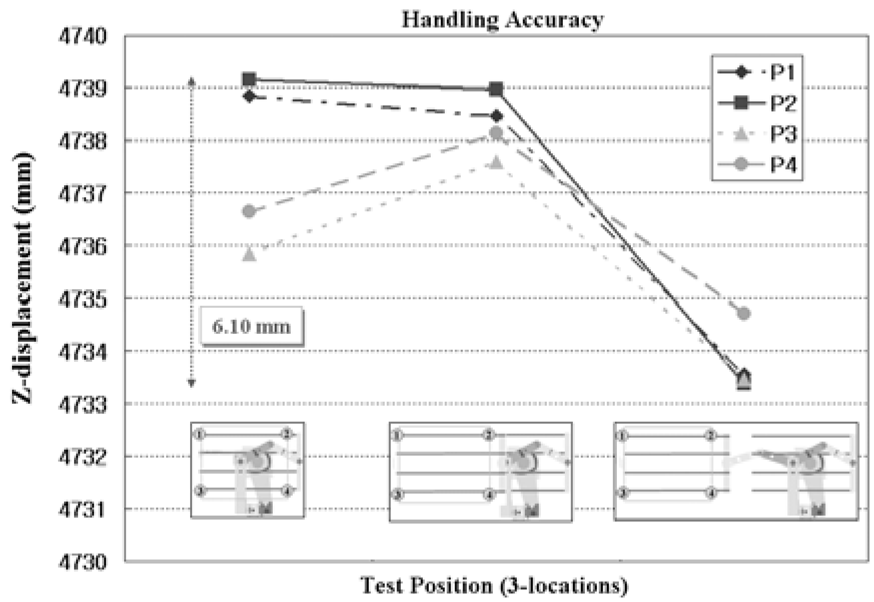


Fig. 17. Test result for vertical deflection

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Die history

1 Die position in industrial production

Mold is a high-volume products with the shape tool, is the main process of industrial production equipment. With mold components, with high efficiency, good quality, low cost, saving energy and raw materials and a series of advantages, with the mold workpieces possess high accuracy, high complexity, high consistency, high productivity and low consumption， other manufacturing methods can not match. Have already become an important means of industrial production and technological development. The basis of the modern industrial economy.

The development of modern industrial and technological level depends largely on the level of industrial development die, so die industry to national economic and social development will play an increasing role. March 1989 the State Council promulgated "on the current industrial policy decision points" in the mold as the machinery industry transformation sequence of the first, production and capital construction of the second sequence (after the large-scale power generation equipment and the corresponding power transmission equipment), establish tooling industry in an important position in the national economy. Since 1997, they have to mold and its processing technology and equipment included in the "current national focus on encouraging the development of industries, products and technologies catalog" and "to encourage foreign investment industry directory." Approved by the State Council, from 1997 to 2000, more than 80 professional mold factory owned 70% VAT refund of preferential policies to support mold industry. All these have fully demonstrated the development of the State Council and state departments tooling industry attention and support. Mold around the world about the current annual output of 60 billion U.S. dollars, Japan, the United States and other industrialized countries die of industrial output value of more than machine tool industry, beginning in 1997, China's industrial output value has exceeded the mold machine tool industry output.

According to statistics, home appliances, toys and other light industries, nearly 90% of the parts are integrated with production of chopsticks; in aircraft, automobiles, agricultural machinery and radio industries, the proportion exceeded 60%. Such as aircraft manufacturing, the use of a certain type of fighter dies more than 30,000 units, of which the host 8000 sets, 2000 sets of engines, auxiliary 20 000 sets. From the output of view, since the 80's, the United States, Japan and other industrialized countries die industry output value has exceeded the machine tool industry, and there are still rising. Production technology, according to the International Association predicts that in 2000, the product best pieces of rough 75%, 50% will be finished mold completed; metals, plastics, ceramics, rubber, building materials and other industrial products, most of the mold will be completed in more than 50% metal plates, more than 80% of all plastic products, especially through the mold into.

2 The historical development of mold

The emergence of mold can be traced back thousands of years ago, pottery and bronze foundry, but the large-scale use is with the rise of modern industry and developed.

The 19th century, with the arms industry (gun's shell), watch industry, radio industry, dies are widely used. After World War II, with the rapid development of world economy, it became a mass production of household appliances, automobiles, electronic equipment, cameras, watches and other parts the best way. From a global perspective, when the United States in the forefront of stamping technology - many die of advanced technologies, such as simple mold, high efficiency, mold, die and stamping the high life automation, mostly originated in the United States; and Switzerland, fine blanking, cold in Germany extrusion technology, plastic processing of the Soviet Union are at the world advanced. 50's, mold industry focus is based on subscriber demand, production can meet the product requirements of the mold. Multi-die design rule of thumb, reference has been drawing and perceptual knowledge, on the design of mold parts of a lack of real understanding of function. From 1955 to 1965, is the pressure processing of exploration and development of the times - the main components of the mold and the stress state of the function of a mathematical sub-bridge, and to continue to apply to on-site practical knowledge to make stamping technology in all aspects of a leap in development. The result is summarized mold design principles, and makes the pressure machine, stamping materials, processing methods, plum with a structure, mold materials, mold manufacturing method, the field of automation devices, a new look to the practical direction of advance, so that pressing processing apparatus capable of producing quality products from the first stage.

Into the 70's to high speed, launch technology, precision, security, development of the second stage. Continue to emerge in this process a variety of high efficiency, business life, high-precision multi-functional automatic school to help with. Represented by the number of working places as much as other progressive die and dozens of multi-station transfer station module. On this basis, has developed both a continuous pressing station there are more slide forming station of the press - bending machine. In the meantime, the Japanese stand to the world's largest - the mold into the micron-level precision, die life, alloy tool steel mold has reached tens of millions of times, carbide steel mold to each of hundreds of millions of times p minutes for stamping the number of small presses usually 200 to 300, up to 1200 times to 1500 times. In the meantime, in order to meet product updates quickly, with the short duration (such as cars modified, refurbished toys, etc.) need a variety of economic-type mold, such as zinc alloy die down, polyurethane rubber mold, die steel skin, also has been very great development.

From the mid-70s so far can be said that computer-aided design, supporting the continuous development of manufacturing technology of the times. With the precision and complexity of mold rising, accelerating the production cycle, the mold industry, the quality of equipment and personnel are required to improve. Rely on common processing equipment, their experience and skills can not meet the needs of mold. Since the 90's, mechanical and electronic technologies in close connection with the development of NC machine tools, such as CNC wire cutting machine, CNC EDM, CNC milling, CNC coordinate grinding machine and so on. The use of computer automatic programming, control CNC machine tools to improve the efficiency in the use and scope. In recent years, has developed a computer to time-sharing by the way a group of direct management and control of CNC machine tools NNC system.

With the development of computer technology, computers have gradually into the mold in all areas, including design, manufacturing and management. International Association for the Study of production forecasts to 2000, as a means of links between design and manufacturing drawings will lose its primary role. Automatic Design of die most fundamental point is to establish the mold standard and design standards. To get rid of the people of the past, and practical experience to judge the composition of the design center, we must take past experiences and ways of thinking, for series, numerical value, the number of type-based, as the design criteria to the computer store. Components are dry because of mold constitutes a million other differences, to come up with a can adapt to various parts of the design software almost impossible. But some products do not change the shape of parts, mold structure has certain rules, can be summed up for the automatic design of software. If a Japanese company's CDM system for progressive die design and manufacturing, including the importation of parts of the figure, rough start, strip layout, determine the size and standard templates, assembly drawing and parts, the output NC program (for CNC machining Center and line cutting program), etc., used in 20% of the time by hand, reduce their working hours to 35 hours; from Japan in the early 80s will be three-dimensional cad / cam system for automotive panel die. Currently, the physical parts scanning input, map lines and data input, geometric form, display, graphics, annotations and the data is automatically programmed, resulting in effective control machine tool control system of post-processing documents have reached a high level; computer Simulation (CAE) technology has made some achievements. At high levels, CAD / CAM / CAE integration, that data is integrated, can transmit information directly with each other. Achieve network. Present. Only a few foreign manufacturers can do it.

3 China's mold industry and its development trend

Due to historical reasons for the formation of closed, "big and complete" enterprise features, most enterprises in China are equipped with mold workshop, in factory matching status since the late 70s have a mold the concept of industrialization and specialization of production. Production efficiency is not high, poor economic returns. Mold production industry is small and scattered, cross-industry, capital-intensive, professional, commercial and technical management level are relatively low.

According to incomplete statistics, there are now specialized in manufacturing mold, the product supporting mold factory workshop (factory) near 17 000, about 600 000 employees, annual output value reached 20 billion yuan mold. However, the existing capacity of the mold and die industry can only meet the demand of 60%, still can not meet the needs of national economic development. At present, the domestic needs of large, sophisticated, complex and long life of the mold also rely mainly on imports. According to customs statistics, in 1997 630 million U.S. dollars worth of imports mold, not including the import of mold together with the equipment; in 1997 only 78 million U.S. dollars export mold. At present the technological level of China Die & Mould Industry and manufacturing capacity, China's national economy in the weak links and bottlenecks constraining sustainable economic development.

3.1 Research on the Structure of industrial products mold

In accordance with the division of China Mould Industry Association, China mold is divided into 10 basic categories, which, stamping die and plastic molding two categories accounted for the main part. Calculated by output, present, China accounts for about 50% die stamping, plastic molding die about 20%, Wire Drawing Die (Tool) about 10% of the world's advanced industrial countries and regions, the proportion of plastic forming die die general of the total output value 40%.

Most of our stamping die mold for the simple, single-process mode and meet the molds, precision die, precision multi-position progressive die is also one of the few, die less than 100 million times the average life of the mold reached 100 million times the maximum life of more than accuracy 3 ~ 5um, more than 50 progressive station, and the international life of the die 600 million times the highest average life of the die 50 million times compared to the mid 80s at the international advanced level.

China's plastic molding mold design, production technology started relatively late, the overall level of low. Currently a single cavity, a simple mold cavity 70%, and still dominant. A sophisticated multi-cavity mold plastic injection mold, plastic injection mold has been able to multi-color preliminary design and manufacturing. Mould is about 80 million times the average life span is about, the main difference is the large deformation of mold components, excess burr side of a large, poor surface quality, erosion and corrosion serious mold cavity, the mold cavity exhaust poor and vulnerable such as, injection mold 5um accuracy has reached below the highest life expectancy has exceeded 20 million times, the number has more than 100 chamber cavity, reaching the mid 80s to early 90s the international advanced level.

3.2 mold Present Status of Technology

Technical level of China's mold industry currently uneven, with wide disparities. Generally speaking, with the developed industrial countries, Hong Kong and Taiwan advanced level, there is a large gap.

The use of CAD / CAM / CAE / CAPP and other technical design and manufacture molds, both wide application, or technical level, there is a big gap between both. In the application of CAD technology design molds, only about 10% of the mold used in the design of CAD, aside from drawing board still has a long way to go; in the application of CAE design and analysis of mold calculation, it was just started, most of the game is still in trial stages and animation; in the application of CAM technology manufacturing molds, first, the lack of advanced manufacturing equipment, and second, the existing process equipment (including the last 10 years the introduction of advanced equipment) or computer standard (IBM PC and compatibles, HP workstations, etc.) different, or because of differences in bytes, processing speed differences, differences in resistance to electromagnetic interference, networking is low, only about 5% of the mold manufacturing equipment of recent work in this task; in the application process planning CAPP technology, basically a blank state, based on the need for a lot of standardization work; in the mold common technology, such as mold rapid prototyping technology, polishing, electroforming technologies, surface treatment technology aspects of CAD / CAM technology in China has just started. Computer-aided technology, software development, is still at low level, the accumulation of knowledge and experience required. Most of our mold factory, mold processing equipment shop old, long in the length of civilian service, accuracy, low efficiency, still use the ordinary forging, turning, milling, planing, drilling, grinding and processing equipment, mold, heat treatment is still in use salt bath, box-type furnace, operating with the experience of workers, poorly equipped, high energy consumption. Renewal of equipment is slow, technological innovation, technological progress is not much intensity. Although in recent years introduced many advanced mold processing equipment, but are too scattered, or not complete, only about 25% utilization, equipment, some of the advanced functions are not given full play.

Lack of technology of high-quality mold design, manufacturing technology and skilled workers, especially the lack of knowledge and breadth, knowledge structure, high levels of compound talents. China's mold industry and technical personnel, only 8% of employees 12%, and the technical personnel and skilled workers and lower the overall skill level. Before 1980, practitioners of technical personnel and skilled workers, the aging of knowledge, knowledge structure can not meet the current needs; and staff employed after 80 years, expertise, experience lack of hands-on ability, not ease, do not want to learn technology. In recent years, the brain drain caused by personnel not only decrease the quantity and quality levels, and personnel structure of the emergence of new faults, lean, make mold design, manufacturing difficult to raise the technical level.

3.3 mold industry supporting materials, standard parts of present condition

Over the past 10 years, especially the "Eighth Five-Year", the State organization of the ministries have repeatedly Material Research Institute, universities and steel enterprises, research and development of special series of die steel, molds and other mold-specific carbide special tools, auxiliary materials, and some promotion. However, due to the quality is not stable enough, the lack of the necessary test conditions and test data, specifications and varieties less, large molds and special mold steel and specifications are required for the gap. In the steel supply, settlement amount and sporadic users of mass-produced steel supply and demand contradiction, yet to be effectively addressed. In addition, in recent years have foreign steel mold set up sales outlets in China, but poor channels, technical services support the weak and prices are high, foreign exchange settlement system and other factors, promote the use of much current.

Mold supporting materials and special techniques in recent years despite the popularization and application, but failed to mature production technology, most still also in the exploratory stage tests, such as die coating technology, surface treatment technology mold, mold guide lubrication technology Die sensing technology and lubrication technology, mold to stress technology, mold and other anti-fatigue and anti-corrosion technology productivity has not yet fully formed, towards commercialization. Some key, important technologies also lack the protection of intellectual property.

China's mold standard parts production, the formation of the early 80s only small-scale production, standardization and standard mold parts using the coverage of about 20%, from the market can be assigned to, is just about 30 varieties, and limited to small and medium size. Standard punch, hot runner components and other supplies just the beginning, mold and parts production and supply channels for poor, poor accuracy and quality.

3.4 Die & Mould Industry Structure in Industrial Organization

China's mold industry is relatively backward and still could not be called an independent industry. Mold manufacturer in China currently can be divided into four categories: professional mold factory, professional production outside for mold; products factory mold factory or workshop, in order to supply the product works as the main tasks needed to die; die-funded enterprises branch, the organizational model and professional mold factory is similar to small but the main; township mold business, and professional mold factory is similar. Of which the largest number of first-class, mold production accounts for about 70% of total output. China's mold industry, decentralized management system. There are 19 major industry sectors manufacture and use of mold, there is no unified management of the department. Only by China Die & Mould Industry Association, overall planning, focus on research, cross-sectoral, inter-departmental management difficulties are many.

Mold is suitable for small and medium enterprises organize production, and our technical transformation investment tilted to large and medium enterprises, small and medium enterprise investment mold can not be guaranteed. Including product factory mold shop, factory, including, after the transformation can not quickly recover its investment, or debt-laden, affecting development.

Although most products factory mold shop, factory technical force is strong, good equipment conditions, the production of mold levels higher, but equipment utilization rate.

Price has long been China's mold inconsistent with their value, resulting in mold industry "own little economic benefit, social benefit big" phenomenon. "Dry as dry mold mold standard parts, standard parts dry as dry mold with pieces of production. Dry with parts manufactured products than with the mold" of the class of anomalies exist.

4 Die trend

4.1 mold CAD / CAE / CAM being integrated, three-dimensional, intelligent and network direction

（**1**）mold software features integrated

Die software features of integrated software modules required relatively complete, while the function module using the same data model, in order to achieve Syndicated news management and sharing of information to support the mold design, manufacture, assembly, inspection, testing and production management of the entire process to achieve optimal benefits. Series such as the UK Delcam's software will include a surface / solid geometric modeling, engineering drawing complex geometry, advanced rendering industrial design, plastic mold design expert system, complex physical CAM, artistic design and sculpture automatic programming system, reverse engineering and complex systems physical line measurement systems. A higher degree of integration of the software includes: Pro / ENGINEER, UG and CATIA, etc.. Shanghai Jiaotong University, China with finite element analysis of metal plastic forming systems and Die CAD / CAM systems; Beijing Beihang Haier Software Ltd. CAXA Series software; Jilin Gold Grid Engineering Research Center of the stamping die mold CAD / CAE / CAM systems .

（2）mold design, analysis and manufacture of three-dimensional

Two-dimensional mold of traditional structural design can no longer meet modern technical requirements of production and integration. Mold design, analysis, manufacturing three-dimensional technology, paperless software required to mold a new generation of three-dimensional, intuitive sense to design the mold, using three-dimensional digital model can be easily used in the product structure of CAE analysis, tooling manufacturability evaluation and CNC machining, forming process simulation and information management and sharing. Such as Pro / ENGINEER, UG and CATIA software such as with parametric, feature-based, all relevant characteristics, so that mold concurrent engineering possible. In addition, Cimatran company Moldexpert, Delcam's Ps-mold and Hitachi Shipbuilding of Space-E/mold are professional injection mold 3D design software, interactive 3D cavity, core design, mold base design configuration and typical structure . Australian company Moldflow realistic three-dimensional flow simulation software MoldflowAdvisers been widely praised by users and applications. China Huazhong University of Science have developed similar software HSC3D4.5F and Zhengzhou University, Z-mold software. For manufacturing, knowledge-based intelligent software function is a measure of die important sign of advanced and practical one. Such as injection molding experts Cimatron's software can automatically generate parting direction based parting line and parting surface, generate products corresponding to the core and cavity, implementation of all relevant parts mold, and for automatically generated BOM Form NC drilling process, and can intelligently process parameter setting, calibration and other processing results.

（3）mold software applications, networking trend

With the mold in the enterprise competition, cooperation, production and management, globalization, internationalization, and the rapid development of computer hardware and software technology, the Internet has made in the mold industry, virtual design, agile manufacturing technology both necessary and possible. The United States in its "21st Century Manufacturing Enterprise Strategy" that the auto industry by 2006 to achieve agile manufacturing / virtual engineering solutions to automotive development cycle shortened from 40 months to 4 months.

4.2 mold testing, processing equipment to the precise, efficient, and multi-direction

（1） mold testing equipment more sophisticated, efficient

Sophisticated, complex, large-scale mold development, testing equipment have become increasingly demanding. Precision Mould precision now reached 2 ~ 3μm, more domestic manufacturers have to use Italy, the United States, Japan and other countries in the high-precision coordinate measuring machine, and with digital scanning. Such as Dongfeng Motor Mould Factory not only has the capacity 3250mm × 3250mm Italian coordinate measuring machine, also has a digital photography optical scanner, the first in the domestic use of digital photography, optical scanning as a means of spatial three-dimensional access to information, enabling the establishment from the measurement of physical → model output of engineering drawings → → the whole process of mold making, reverse engineering a successful technology development and applications. This equipment include: second-generation British Renishaw high-speed scanners (CYCLON SERIES2) can be realized and contact laser probe complementary probe, laser scanner accuracy of 0.05mm, scanning probe contact accuracy of 0.02 mm. Another German company GOM ATOS portable scanners, Japan Roland's PIX-30, PIX-4 desktop scanner and the United Kingdom Taylor Hopson's TALYSCAN150 multi-sensor, respectively Three-dimensional scanner with high speed, low-cost and functional composite and so on.

（2）CNC EDM

Japan Sodick linear motor servo drive using the company's AQ325L, AQ550LLS-WEDM have driven fast response, transmission and high positioning accuracy, the advantages of small thermal deformation. Switzerland Chanmier company NCEDM with P-E3 adaptive control, PCE energy control and automatic programming expert systems. Others also used the powder mixed EDM machining technology, micro-finishing pulse power and fuzzy control (FC) technologies.

（3）high-speed milling machine (HSM)

Milling is an important means of cavity mold. The low-temperature high-speed milling with the workpiece, cutting force is small, smooth processing, processing quality, processing efficiency (for the general milling process 5 to 10 times) and can process hard materials (<60HRC) and many other advantages. Thus in the mold processing more and more attention. Ruishikelang company UCP710-type five-axis machining center, machine tool positioning accuracy up to 8μm, home-made closed-loop vector control spindle with a maximum speed 42000r/min. Italy RAMBAUDI's high-speed milling, the processing range of up to 2500mm × 5000mm × 1800mm, speed up 20500r/min, cutting feed speed of 20m/min. HSM generally used large, medium-sized mold, such as motor cover mold, die casting mold, large plastic surface machining, the surface precision up to 0.01mm.

4. 3 rapid economic modeling techniques

Shorten the product development cycle is an effective means of market competition to win one. Compared with the traditional mold process, fast economic modeling technology is a short molding cycle, the characteristics of low cost, precision, and life can meet the production needs, overall economic efficiency is more significant in the mold manufacturing technology, specifically the following main technology.

（1） rapid prototyping and manufacturing (RPM). It consists of three-dimensional laser lithography (SLA); laminated profile manufacturing (LOM); laser powder sintering prototyping (SLS); Fused Deposition Molding (FDM) and three-dimensional printing forming technology (3D-P) and so on.

（2）the surface forming tooling. It refers to the use of spray, chemical corrosion, electroforming and new method for the formation of the cavity surface and a fine pattern technology.

（3）Casting forming tooling. There are bismuth tin alloy tooling, zinc alloy tooling, resin composite forming technology and silicon rubber mold molding technology.

（4）cold extrusion mold technology and ultra-molded shapes.

（5）multi-point forming technology.

（6） KEVRON steel blanking blanking tooling.

（7）mold blank rapid manufacturing technology. Mainly dry sand Mold Casting, Vacuum Mold Casting, Resin Sand Mold Casting Lost Wax Casting, and other technologies.

（8）Other aspects of technology. Such as the use of nitrogen gas spring pressure side, discharge, quick die technology, stamping unit technology, and cutting edge technology and solid surfacing edge inserts die casting technology.

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