Dynamic Modeling for the Main Transmission System of Ship-lift Based on Sub-structure Method

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Abstract: Three gorges Ship-lift is a very complicated system, so it is very difficult to establish a dynamic model directly for the integrated system. Therefore, the sub-structure method is introduced to study the system in this paper. Here, the integrated system, which describes the main transmission system of the Ship-lift, is divided into eight first-class sub-systems which is very similar each other, then each first-class sub-system is divided into three second-class sub-systems again. They are sub-structure b which describes the motor and the reducer, sub-structure c (or d) which illustrates synchronizing axis and sub-structure e which describe the rollers, the torque balanceable heavy, the Loading Ship-box, the gravity balanceable heavy and the pulley. Under supposed conditions, the dynamic models of all second-class sub-structure were established. Those dynamic models are restricted by boundary coupling conditions. Then, these equations are assembled into one integrated matrix according to the boundary coupling conditions and other coupling conditions. Eventually, an integrated dynamics equation which describes all parts of main transmission system is established. After the whole dynamic equations had been established, the parameters of the system were embodied through a series of calculation. All of the boundaries coupling conditions need to be determined too. They include displacement coupling conditions and force coupling conditions which exists in either part inside or between two parts. Subsequently, the Wilson θ expressions were chosen as the iterative method to simulate the Ship-lift dynamic system. When $\theta \geq 1.37$, the system is in unconditioned stabilization. Through analyzing on the simulated data, a conclusion can be draw that these dynamic equations describe dynamic performances of the main transmission system exactly, and the primary plan is also reasonable.

Key words: Ship-lift, Sub-structure, Synchronization-axis

1 Introduction

Type of the Ship-lift which is on designing is all-balanceable. All the balanceable heavy are divided into two parts: one kind of heavy is gravity balanceable heavy (9300 tons), and another is torque balanceable heavy (2500 tons) [1]. Gravity balanceable heavy whose weight is almost equal to the water's weight loaded in the loading-ship-box, is linked to loading-ship-box through pulley block whose diameter is 5.6 meters by 144 steel wire ropes, while torque balanceable heavy whose weight is almost equal to the weight of loading-ship-box, is linked to one end of 48 steel wire ropes, another end of the 48 steel wire ropes are wrapped in two rollers whose diameter is 5.6 meters too. And the counterpart 48 steel wire ropes whose direction of roll out of the rollers, are averse to the balanceable ropes, are linked to loading-ship-box through hydraulic pressure balance system; they share steel wire rope's grooves of the rollers, and make up of torque balanceable system together. Each steel wire rope is pulled evenly by the means of mechanics and hydraulic.

2 Physical Model of the Main Transmission System of Ship-lift

The Ship-lift main transmission system may be divided into eight symmetrical parts. Every symmetrical part include: one motor, one reducer, one synchronization-axis, two rollers, six gravity balanceable heavies, six torque balanceable heavies, six pairs pulleys, and six units of loading-ship-box(each unit is 1/24 of the whole loading-ship-box) . The schematic diagram of 1/4 system is shown as Fig.1:

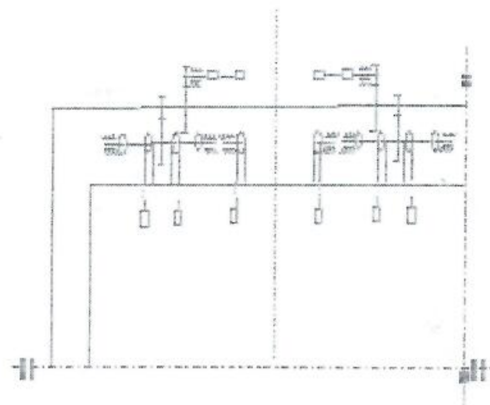

Figure 1 Schematic Diagram of 1/4 System

3 The Methodology of Building Mathematic Model of the Main Transmission System

The Three-gorge Ship-lift is a very complicated system. So it is very difficult to establish directly a dynamic model for whole studied system. Therefore, sub-structure method is introduced to study the system, namely the whole system is divided into several part which is called a sub-structure or a sub-system [2] [3] [4]. Then, dynamic model of each sub-structure is established, after that, according to joint conditions of every sub-structure, they are coupled to together, eventually, the dynamic model of the whole system will be obtained.

The Three-gorge Ship-lift main transmission system may be divided into 8 first class sub-structures which is divided into 3 second class sub-structures again: sub-structure b includes one motor and one reducer; sub-structure c(or d) is synchronization-axis; sub-structure e includes one roller, one unit gravity balanceable heavy, one unit torque balanceable heavy, pulley block and loading-ship-box. According to the difference of length of synchronization-axis here, they are divided into short lengthways synchronization-axis d1, long lengthways synchronization-axis d2 and transverse synchronization-axis c. Every first class sub-structure has two identical sub-structure e.

4 Hypothesis on the Dynamic System Model

Before establishing dynamic model of the sub-structure system, in order to catch hold of the primary contradicts of the question; just consider system as pure torsion vibration system. Mean while, others hypotheses are done as follows: Damp of whole system is regarded as proportional damp of structural damp; neither considers the coupling between machine and electricity, nor the coupling between liquid and solid; No considering the nonlinear effect of tight wires; No considering stirring oil error or air damp.

5 Sub-structure b (Motor and Reducer)

Shown as Fig.2, the model of sub-structure b is established by means of centralizing mass method. Each axis and gear in the sub-structure b is transformed as equivalent element of turning inertia; each turning axis is transformed as equivalent elastic element. Then each class equivalent inertia moment as well as equivalent rigidity is transformed to the motor axis. Meantime, the mesh rigidity of every pair gears and mesh damp are thought over [5] [6]. Thus, the multi-degree of freedom torque vibration systems which is transformed from sub-structure b is obtained. The second axis of the reducer links to the synchronization-axis (sub-structure c and sub-structure d), the sixth axis of the reducers links to the axis of the roller (sub-structure e). According to Newton law, every turning degree of freedom motion differential equation can be obtained:

$$J^b\ddot{\theta}^b + C^b\dot{\theta}^b + K^b\theta^b = T^b \qquad (1)$$

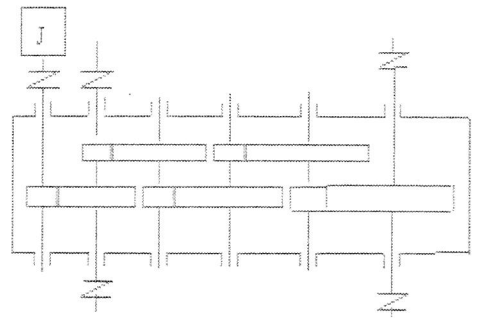

Figure 2 Schematic Diagram of the Sub-structure b

5.1 Sub-structure c, d (Synchronization-axis)

The synchronization-axes are divided into three kinds of types; they are transverse synchronization-axis c, short lengthways synchronization-axis d1 and long lengthways synchronization-axis d2. On the assumption that the transverse synchronization-axis is even material, according to the thought of finite element method, it is divided into ten equal elements, and the turning inertia of every element respectively congregate to it's two sides, because just turning vibration is thought over, the degrees of freedom of the eleven ends are eleven too, then , the quality matrix and rigidity matrix of every element can be written, damp of each element is supposed as structure damp(proportion damp); then the displacement corresponding conditions and balance conditions are thought over, these equations can be assembled into one. The mechanic model sketch of this sub-structure can be described as figure 3 [7]. The motion differential equation of the transverse synchronization-axis of the sub-structure c is:

$$M^c\ddot{\theta}^c + C^c\dot{\theta}^c + K^c\theta^c = T^c \qquad (2)$$

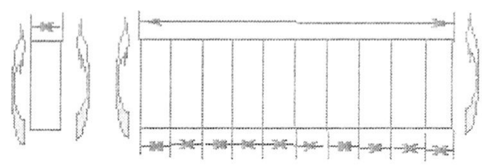

Figure 3 (transverse synchronization-axis) mechanics model sketch of sub-structure c (ichnography)

5.2 Sub-structure e (roller, torque balanceable heavy, loading-ship-box, gravity balanceable heavy and pulley)

The sub-structure e is made of one roller, torque balanceable heavy (1/16 of the whole), loading-ship-box (1/16 of the whole), gravity balanceable heavy (1/16 of the whole one) and pulley block (1/16 of the whole one). One first class sub-structure has two identical sub-structure e.

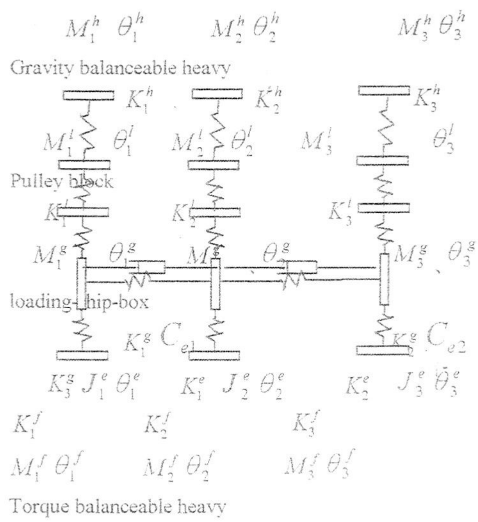

Figure 4 the Sketch of Dynamic Model of Sub-structure e

According to foregoing structural analysis to the Three-gorges Ship-lift, The similar analytical method with finite element is used in roller mechanics analysis, by this method, the whole roller is divided into three equal parts, every part is replaced with concentrated quality element, every part of the roller is linked to torque balanceable heavy and loading-ship-box, and the loading-ship-box is also linked to the gravity balanceable heavy. Thus, according to the mechanic model sketch of sub-structure e as well as the supposed damp as figure 4, damp matrix can be obtained, then according to Newton motion law again, the motion differential equation of sub-structure e is given. That is:

$$M^e\ddot{\theta}^e + C^e\dot{\theta}^e + K^e\theta^e = T^e \qquad (3)$$

5.3 Power row matrix

The coupled power row matrix is:

$$T = [T_i]^T \quad i = (1 \sim 360),$$

where T_1、T_{46}、T_{91}、T_{136}、T_{190}、T_{235}、T_{280}、T_{325} is respectively equal with the output torque of the motor, and the other value is zero. Then, every sub-system is arranged according to the sequence of the main transmission system. Finally, a whole equation is built into one system with 392 degrees of freedom, its mass matrix is M_Z, the rigidity matrix is K_z, and the damp matrix is C_Z, before coupling, the whole motion equation is:

$$M_z\ddot{\theta}_z + C_z\dot{\theta}_z + K_z\theta_z = T_z \qquad (4)$$

But among this equation, there are 32 dependent coordinates, they should be removed.

After that, the means of rigidity integration is adopted to couple with every sub-structures, every sub-structures meet displacement consistent conditions and acting power equation conditions, then the coordinates transform matrix S is educed from (the substance process is omitted). The rank of coupling matrix S of joint interfaces of all sub-system is 392*360 , then one matrix whose rank is 360*360 is obtained by coordinates transform, that is:

$$\theta = S^T\theta_z; T = S^T T_z;$$
$$M = S^T M_z S \quad C = S^T C_z S; \qquad (5)$$

5.4 Dynamic equation of the whole system

$$M\ddot{\theta} + C\dot{\theta} + K\theta = T \qquad (6)$$

where $\theta = S^T\theta_z$; $T = S^T T_z$; $M = S^T M_z S$; $C = S^T C_z S$, $K = S^T K_z S$.

Now works for building model have been finished. Afterwards, we are going to work on preferences and simulation. then mode analysis will be given. We will optimize design by analysis so that the Ship-lift can do work normally under given work conditions.

6 Simulation

6.1 Simulating algorithm

In this paper, Wilson θ algorithm was introduced as iterative arithmetic. This arithmetic takes Newmark algorithm of linear acceleration as basis, it introduces a parameter θ ,where θ >=1.in time-domain range of t+ θ * Δ t, the acceleration is supposed to be linearly variable. We may deduce a set of mathematic equations where instantaneous time is t+ θ * Δ t. And then we may deduce revised equations of displacement, speed and acceleration in t+ θ * Δ t time. When θ >=1.37, Wood proved Wilson θ method to be unconditionally jarless. The iterative equations of Wilson θ method are as follows:

$$\{\ddot{x}_{n+1}\} = \frac{6}{\theta^3\Delta t^2}\left(\{x_{n+\theta}\} - \{x_n\}\right) - \frac{6}{\theta^2\Delta t}\{\dot{x}_n\} + \left(1 - \frac{3}{\theta}\right)\{\ddot{x}_n\}$$

$$\{\dot{x}_{n+1}\} = \{\dot{x}_n\} + \frac{\Delta t}{2}\left(\{\ddot{x}_{n+1}\} + \{\ddot{x}\}\right)$$

$$\{x_{n+1}\} = \{x_n\} + \Delta t\{\dot{x}_n\} + \frac{\Delta t^2}{6}\left(\{\ddot{x}_{n+1}\} + 2\{\ddot{x}_n\}\right) \qquad (7)$$

6.2 Simulating results

By simulating calculation, we got a lot of useful data. The qualitative analysis could be conducted by using relative mechanics theories. We also compared these simulating data with data tested from other already operating Ship-lift system. These analyses may efficiently direct us ameliorating the dynamic model of the Three-gorge Ship-lift. Because there are many simulated data, we chose some typical data and showed them from Fig 5 to Fig13 and Table 1.

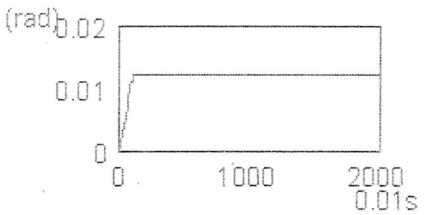

Fig 5 vibrating displacement of axis of the electromotor (1)

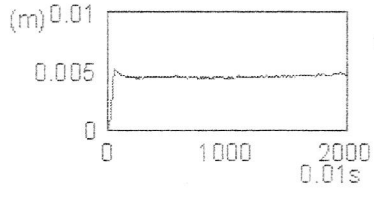

Fig 6 vibrating displacement of the Loading Ship-box (15)

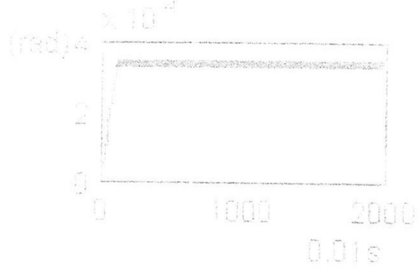

Fig 7 vibrating displacement of short lengthways synchronization-axis (41)

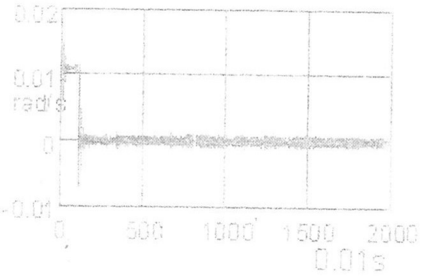

Fig 8 vibrating speed of axis of the electromotor (1)

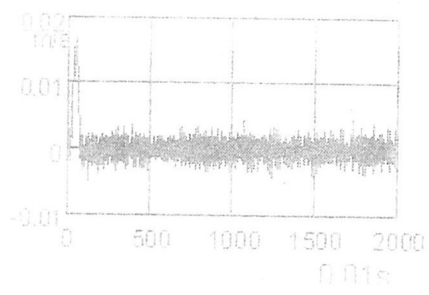

Fig 9 vibrating speed of the Loading Ship-box (15)

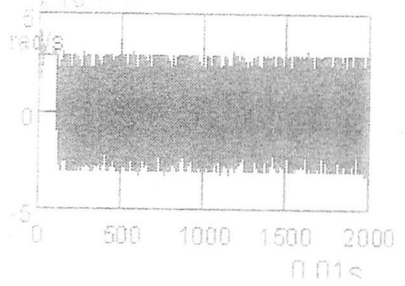

Fig 10 vibrating speed of the short lengthways synchronization-axis (41)

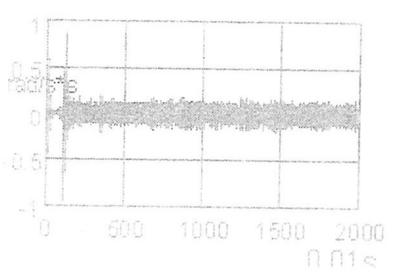

Fig 11 vibrating acceleration of axis of the electromotor (1)

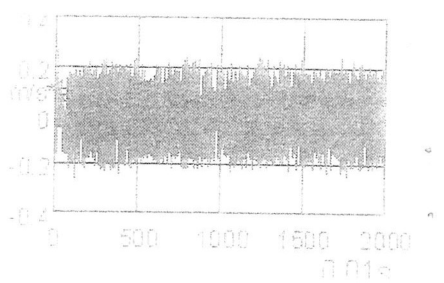

Fig 12 vibrating acceleration of the Loading Ship-box (15)

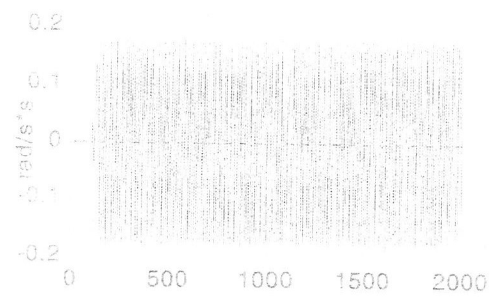

Fig 13 vibrating acceleration of the short lengthways synchronization-axis (41)

Table 1 the simulated data of some parts

degree of freedom	maximum value of vibrating displacement	maximum value of vibrating speed	maximum value of vibrating acceleration
Axis ofelectromotor (1)	0.0125rad	0.002rad/s	0.25rad/s^2
Loading Ship-box (15)	5.15×10-3m	4.5×10-3m/s	0.25m/s^2
short lengthways synchronization-axis (41)	3.5×10-4rad	3×10-4rad/s	0.18rad/s^2

6.3 Simulating analysis

6.3.1 Vibration displacement

The output power of electromotor is 9550*Pe/n/1.14*t in t<1.14s; and in t>=1.14s, it is 9550*Pe/n. So the graph of the vibration displacement of axis of the electromotor is composed of a segment of ascending bias and a segment of beeline in vibration displacement chart "1degree of freedom-electromotor". Because the system is very complicated, and the evaluation of parameters may deviate from the true value, the displacement of axis of electromotor appears too smooth to distortion. Because the synchronization-axis is linked to the second axis of reducer, its displacement characteristic is similar to the one of axis of electromotor. As for high frequency components frequently appear in the fifth axis of the roller and the reducer, we think that the main factors is noise begotten by distortion of parameter. Comparing with high frequency, the low frequency may essentially describe the characteristic of system. Thus this study may draw a common conclusion.

6.3.2 Vibration speed and acceleration

The speed amplitudes and acceleration one of each degree of freedom is very small, so we may regard this system as system of low frequency. As for the high-frequency components which appear frequently in the charts, we think that it maybe contributed by calculating error and high-order frequency.

7 Conclusion

A dynamic model built for Yantan Ship-lift made sure the validity of this method of modeling. In the simulation of Three-gorge Ship-lift, the result of simulation was well-pleasing. So we draw two conclusions:

- This kind of method of modeling may work very well.
- The primary design of the Three-gorge Ship-lift is reasonable.

Acknowledgment

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