Structural dynamics of big gantry crane subjected to different trolley move laws

L Solazzi$^1$ and M Cima

DIMI Department of Mechanical and Industrial Engineering, Via Branze 38 Brescia

$^1$corresponding author - luigi.solazzi@unibs.it

Abstract. The present work concerns the oscillations and therefore the displacements present on a portal crane in the case in which the trolley is moved with different laws and in particular with different maximum accelerations. The work also investigates the effects of an abrupt stop of the trolley movement and also how the load oscillations, following the stop of the trolley movement, generates vibrations in the crane structure which are correlated to the crane natural frequencies. The work was developed on a real geometry of portal cranes using the finite element method. A new procedure was developed and implemented to simulate variable forces on the crane i.e. the forces induced by the trolley movement. The results show that in determinate conditions, the displacement and therefore the relative oscillations are very significant and therefore cannot be neglected.

Keywords
Crane, movement law; vibration, numerical procedure.

Introduction
Lifting and transport devices are subject to different load conditions, defined by different standards that include wind actions [1,2], actions induced by seismic effects [3], effects induced by application and load release [4,5] in particular the application or removal of load on lifting apparatus generates an over stressing whose magnitude depends on numerous factors, such as the lifting speed, the stiffness of the structure and the damping coefficient of the structure itself [6]; if the application of the load occurs at a very high speed, the increase in displacements and therefore stresses becomes very high [7]. The gantry cranes as well as having an increase in the actions induced by the lifting of the load, there is an increase in the actions as a consequence of the movement of the load on the girder of the bridge crane. There is, in the literature, a lot of documents concerning the actions to be implemented on the bridge crane, and in particular to the trolley movement in order to limit the load oscillation. The latest phenomenon has huge repercussions with both hooking and unloading times. However, the actions that the trolley induces on the structure also in terms of stress and vibrations are not there. In [8, 9] some solutions are developed in a discrete way that allow to highlight the actions on the crane.
In this perspective the present work is inserted with the purpose of define a calculation procedure, to be implemented through the finite element technique, in order to study the actions that the trolley movement generates on the bridge crane. In particular, the influence in the values of a series of variables (acceleration of the trolley, sudden stop of the trolley and the length of the rope that fixed the load) on the structural behaviour of the machine were then analysed. The work was developed on the basis of the work [10], using the same lifting equipment and comparing the results in terms of displacement obtained with the finite element calculation technique and the results obtained with discrete solutions in [10].

Definition of the crane (principal geometries / characteristics)

Figure 1 shows the solid model of the crane object of this research. This model was developed using the SolidWorks® software. It is a portal crane with a load capacity of 60t, a width of 40m, a height of 15m; at one side there is a column, while on the other side there are two legs. Figure 1 shows both the structure in [10] and the relative solid model developed.

Numerical calculation procedure

The movement of the trolley on the bridge crane body takes place in three different steps. In the first phase, after having lifted the load, the trolley is accelerated until a specific speed is reached that is maintained for a defined time, then there is a deceleration phase necessary to block the trolley. The vertical load always acts on the beam girder, while the horizontal load acts in the phase in which there is the acceleration or deceleration of the trolley itself.

Figure 2 shows this schematization. In particular, the trolley starts to move from the left side to the right side; in the first section it is subjected to an acceleration and so the structure is subjected to forces in the left direction or (-z) these horizontal forces which depend on the acceleration of the trolley is zero in the central part while they have opposite sign (+z) in the final part where the trolley it is decelerated until it stops. The vertical forces are always present as a consequence of the presence of the lifted load.
Figure 2. Figure of a gantry crane and its model

To simulate the handling of the cargo, assigned a specific law, it is necessary to identify some nodes of the structure’s mesh, which according to their position is possible to simulate the passage the load at given moment time.

In particular, a series of forces were applied at certain mesh nodes so that they were variable over time with a triangular pattern, as shown in Figure 3.

Figure 3. Step of the position of the carriage for our simulation

All analyses were performed using the finite element method and in particular the program used was Autodesk Simulation ®. The model was made using quadratic formulation brick elements for a total about $3 \times 10^6$ degree of freedom. At the portal crane base hinges boundary conditions were applied, while the forces were applied to the body according to the procedure described above.

Numerical analyses with variable forces over time can be carried out with two different methods: the first is the modal overlap and the second one by direct integration method [11,12]. For the first method the number of the natural frequencies assumed is fundamental and in particular the modal mass involved; according to some standards, this value must be higher than 80% of the whole mass of the machine. The fundamental parameter for the second solution method is the integration step. Preliminary analyses were carried out comparing the results in order to obtain a convergence in the values adopting the two methodologies. Figure 4 shows the results in terms of displacement in the y and z direction for the two calculation methodologies implemented. Given the substantial convergence and because the computational cost of direct integration method was lower, this technique was chosen for all analyses by adopting an integration step equal to 0.005s. Another parameter that substantially conditions the values of the displacements and therefore of the accelerations is the value of the damping (both for the material and for the structure) on the basis of bibliographic data [13,14] and by experimental analyses [5] value adopted is was 5%.
Figure 4. Movement in the y and z direction for the two solution methods: blue modal overlap; red direct integration.

Acceleration Influence

The trolley moves in the horizontal direction (z) in the central part of the crane and more precisely for 32 m. The trolley acceleration in both the start and stop phases is a fundamental parameter in fact it determines the actions that act on the structure and therefore the relative movements. Three different laws with linear acceleration were assumed and in particular 0.12, 0.6 and 3 m/s² like maximum value. A last load condition was assumed by adopting a polynomial law to describe acceleration. Figure 5 shows two of the analysed load conditions.
Figure 5. Different trends of trolley speed.

It is important to specify that according to the maximum acceleration or the related law, the travel time of the movement changes, as shown in Figure 5. The travel time with an acceleration of 3 m/s² is about 13 s while with a polynomial law is equal to about 22 s; for this in the abscissa of the Figure 6 and 7 the time is a perceptual of total time for translate the trolley on the crane.
Figure 6. Trend in the y-direction for different accelerations: polynomial red, blue 3 m/s^2; green 0.6 m/s^2 and green 0.12 m/s^2.

Figure 7. Trend in the z-direction for different accelerations: polynomial red, blue 3 m/s^2; green 0.6 m/s^2 and green 0.12 m/s^2.

Emergency stop phase.

In the event that there is an emergency braking intervention for any need, the trolley abruptly stops its movement. In this case there is the maximum acceleration and therefore the maximum horizontal force. The law of motion is shown in Figure n° 8, while the movements both in the y direction and in the z direction are shown in Figure n° 9 and Figure 10.
Figure 8. Emergency stop of the movement of the carriage

Figure 9. Movement along the y direction
Figure 10. Movement along the z direction

Effect of the rope

The previous analyses consider the mobile load concentrated on the trolley positioned on the crane horizontal beam. In reality, this load is fixed to the trolley by a rope. When the trolley suddenly stops, the load starts to oscillate "pendulum" whose frequency is obviously according to the rope length. This paragraph, studies the oscillations of the cranes considering the oscillation of the load positioned with different rope length, after an abrupt stop of trolley movement. The calculation method adopted was that of considering a sudden stop of the carriage movement, at which point the load starts to oscillate with a specific frequency. This motion produces centripetal and tangential accelerations, which depending on the angular position of the load, these are transformed into vertical and horizontal forces acting on the structure. Figures n ° 11 and n ° 12 show some determined results with a 3m rope length.

Figure 11 shows the progress of the centripetal and tangential acceleration which, after the abrupt stop, obviously becomes damper as a function of the rope damping coefficient. Figure 12 shows the trend of the movement in the z direction.

Figure 11. Acceleration of the load: tangential blue, centrifugal red
Figure 12. Movement in a z direction for a rope with a length of 3 m.

The procedure described above has been applied to three different rope lengths, i.e. 3m and 17 m as extreme values of the position of the load and 0.216 m (value which is physically impossible) but which generates an oscillation of the load with a frequency equal to the first natural crane frequency.

Figures n° 13 and n° 14 show the movements of the crane in direction y and z in correspondence of the three rope lengths and in the absence of the oscillation induced by the load.

Figure 13. Trend in the y-direction for different rope lengths: light blue L = 0.216m; red L = 3m; black L = 17m and yellow without load oscillation.
Results

From the results reported mainly in graphical form, the motion law with which the trolley is activated indicates the significant vibrations and displacements in the portal crane and that the magnitude of these actions depends strongly on the intensity of the maximum acceleration.

The trolley sudden stop movement generates the maximum acceleration on the structure and therefore the maximum displacement on it.

The displacement of the structure induced by the pendulum of the load is strongly dependent on the length of the rope and in particular when the frequency of oscillation of the load approaches the natural frequency of the crane the effects on the displacement are amplified. It is important to underline that the movements of the crane translate into stresses acting on the various structures and that therefore the translation of the load can generally generate considerable stresses which are added to those induced by the lifting of the load. In this case, failure phenomena due to overturning or even local and / or global buckling phenomena cannot be excluded. The variability of the stresses in the time induced either by the actuation law of the trolley or by the pendulum of the load can induce fatigue phenomena in the structure.

Conclusions

The present numerical research shows a procedure to simulate the actions induced by the load movement by means of the finite element method. The work is concentrated on a portal crane reporting a series of results related to the oscillations and therefore the displacements both in the vertical plane and in the horizontal plane of a portal crane in the case where the trolley suitable for handling the load, subjected to different driving laws.

The research also considers both the exceptional load condition as the abrupt stop of the trolley movement and the action on the structure induced by oscillating load fixed to the trolley with different rope length.

The results show that in certain circumstances of both acceleration and rope length the maximum displacements assume absolutely not negligible values whose respective values of the stresses added to those induced by the lifting of the load must be taken into account in order to avoid dangerous overstress conditions of the structure that can lead to the collapse of the same. The work is being developed
both as regards generalization to other lifting devices and as regards experimental tests to confirm the numerical results obtained.

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