Controlling and Reducing Hazard Exposure to Hand Power Tools Vibration

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Abstract

This paper investigates the combination of hand arm response and the vibration of hand power tools. The model of the hand power tools used in this paper to analyse cumulative sequences from the excitation during the operation is the jack hammer. The user subjected to many diseases during operation of the 'jack hammer such as (sever pain, numbness, pins, needles, loss of sense, and touch, loss of grip strength and painful wrist) .These diseases caused from the successive high amplitudes of vibration transferred from the jack hammer to the hand arm of the user. Results are presented to study the relationship between the excitation and the response of the system with the aid of Ansys program to give the indications of Eigen values and Eigen vectors deformation, to predict the behavior of hand-arm vibration, to control the risks from the vibration of the tool. This indicates that the high amplitudes of the jack hammer can be minimized by adding the dynamic vibration absorber which is a simply-spring mass system to the original mass system to make the system to two degree of freedom system and the entire system will have two Eigen values one above the excitation and the other under the excitation and this leads to eliminate the higher response and will have very small amplitude instead of very large amplitude to protect the users from the risks of hand arm vibration during the operation.

Keywords: Hand-transmitted vibration, risk-assessments, construction tools.

السيطرة وتقليل التعرض لخطر الاهتزاز في ذراع اليد الناتج عن اجهزة العمل اليدوية الاهتزازية

المستخلص

يدرس هذا البحث العلاقة بين استجابة ذراع اليد واجهزة العمل اليدوية الاهتزازية حيث ان النموذج الرياضي المستخدم في هذا البحث يقوم بتحليل الاهتزاز المتعاقب التراكمي الناتج عن الاثارة اثناء اشتغال الجهاز المستعمل في هذه الدراسة وهو "الجك همر" حيث يتعرض المشغل الى العديد من المشاكل مثل (الام حادة في الذراع ,خدر الاصابع, فقدان الحس واللمس , قبضة يد مؤلمة وفقدان التحسس) هذه المشاكل ناجمة من السعات العالية المتتالية المنقولة من الجك همر الى الذراع حيث ان النتائج النظرية التي عرضت تم استخدامها لدراسة العلاقة بين الاثارة والاستجابة للمنظومة بمساعدة برنامج Ansys لبيان المؤشرات التي تعطي الترددات الطبيعية والنسوق والتشوهات المرنة وذلك للتنبؤ بسلوك الذراع المعرض الى الاهتزازات للسيطرة على المخاطر الناجمة من ادوات الاهتزاز حيث تم الاستنتاج الى انه يمكن تقليل السعة العالية للجك همر باضافة جهاز الامتصاص الديناميكي للاهتزازات الذي هو عبارة عن منظومة بسيطة مكونة من نابض وكتلة (منظومة ذات درجة حرية واحدة) الى المنظومة الاصلية لتحويله الى منظومة ذات درجتي حرية حركة وبالتالي يمتلك النظام باكملة ترددين طبيعين احدهما اعلى من تردد الاثارة والاخر ادنى من تردد الاثارة وهذا يؤدي الى الغاء السعة العالية ويكون النظام ذو سعة صغيرة جداً بدلاً من السعة الكبيرة جدا لحماية المستخدمين من مخاطر الاهتزاز خلال عمل الجهاز.

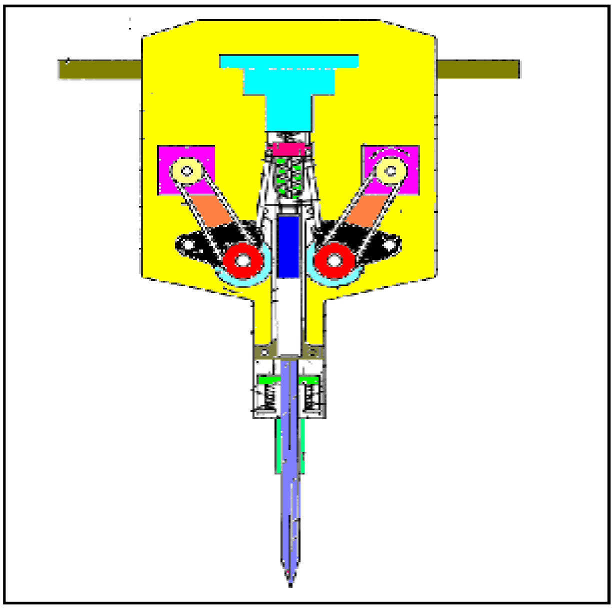
1. Introduction

Hand-arm vibration is a vibration transmitted from work processes into workers' hands and arms. It can be caused by operating hand-held power tools, such as road breakers, and hand-guided equipment, such as powered lawnmowers, or by holding materials being processed by machines, such as pedestal grinders [1, 2]

Jack hammer have been in use for years and are utilized to break up concrete, asphalt and other hard material .A conventional jackhammer is powered by compressed air and emits a significant amount of vibration to the operator .This continued vibration can result in fatigue and possible injury to the operator of the jack hammer .Hence .there is a need for a jackhammer that has a significantly reduced vibration for the operator [3,4].

2. Model analysis

The model used in the present study is the "jack hammer" as shown in figure (1).



Figure(1).Jack hammer geometry [3].

The general equations modeling the multi-degree system of the Systematic representation of jack hammer shown in Figure (2).

$$m_1\ddot{x}_1+(c_1+c_2+c_3+c_4)\dot{x}_1-c_3\dot{x}_2-c_4\dot{x}_3+(k_1+k_2+k_3+k_4+k_5+k_6)x_1+(k_3+k_4)x_2-(k_5+k_6)x_3=F_0\,sin\omega t \quad (1)$$

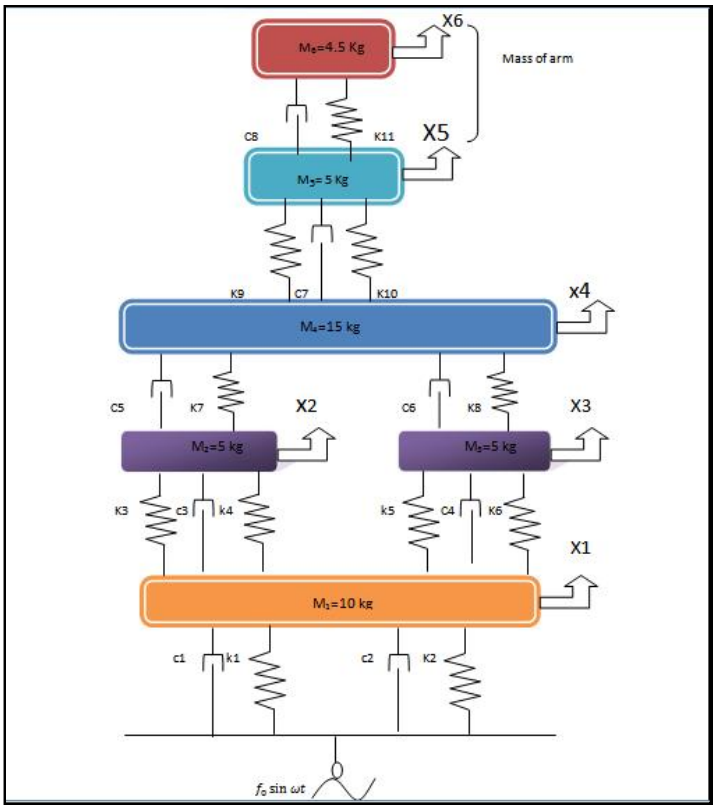
$$m_2\ddot{x}_2+(c_3+c_5)\dot{x}_2-c_3\dot{x}_1-c_5\dot{x}_4+(k_3+k_4+k_7)x_2-(k_3+k_4)-c_7\dot{x}_4=0 \quad (2)$$

$$m_3\ddot{x}_3+(c4+c6)\dot{x}_3-c4\dot{x}_1-c_6\dot{x}_4+(k3+k6+k8)x_3-(k5+k6)x_1-k8x_4=0 \quad (3)$$

$$m_4\ddot{x}_4+(c_5+c_6+c_7)\dot{x}_4-c_5\dot{x}_2-c_6\dot{x}_3+(k_7+k_8+k_9+k_{10})x_4-k_7x_2-k_8x_3-(k_9+k_{10})x_5-c_7\dot{x}_5=0 \quad (4)$$

$$m_5\ddot{x}_5+(c_7+c_8)\dot{x}_5-c_7\dot{x}_4-c_8\dot{x}_6+(k_9+k_{10}+k_{11})x_5-(k_9+k_{10})x_4-k_{11}x_6=0 \quad (5)$$

$$m_6\ddot{x}_6+c_8\dot{x}_6-c_8\dot{x}_5+k_{11}x_6-k_{11}x_5=0 \quad (6)$$



Figure(2). Systematic representation of jack hammer.

Putting equations (1-6) in matrix form

$$\begin{bmatrix} m_1 & 0 & 0 & 0 & 0 & 0 \\ 0 & m_2 & 0 & 0 & 0 & 0 \\ 0 & 0 & m_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & m_4 & 0 & 0 \\ 0 & 0 & 0 & 0 & m_5 & 0 \\ 0 & 0 & 0 & 0 & 0 & m_6 \end{bmatrix} \begin{Bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \\ \ddot{x}_3 \\ \ddot{x}_4 \\ \ddot{x}_5 \\ \ddot{x}_6 \end{Bmatrix} +$$

$$\begin{bmatrix} c_1+c_2+c_3+c_4 & -c_3 & -c_4 & 0 & 0 & 0 \\ -c_3 & c_3+c_5 & 0 & 0 & 0 & 0 \\ -c_4 & 0 & c_4+c_6 & -c_6 & 0 & 0 \\ 0 & -c_5 & -c_6 & c_5+c_6 & -c_7 & 0 \\ 0 & 0 & 0 & -c_7 & c_7+c_8 & -c_8 \\ 0 & 0 & 0 & 0 & -c_8 & c_8 \end{bmatrix} \begin{Bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \\ \dot{x}_5 \\ \dot{x}_6 \end{Bmatrix} +$$

$$\begin{bmatrix} k_1+k_2+k_3+k_4+k_5+k_6 & -(k_3+k_4) & -(k_5+k_6) & 0 & 0 & 0 \\ -(k_3+k_4) & k_3+k_4+k_7 & 0 & -k_7 & 0 & 0 \\ -(k_5+k_6) & 0 & k_3+k_6+k_8 & -k_8 & 0 & 0 \\ 0 & -k_7 & -k_8 & k_7+k_8+k_9+k_{10} & -k_9-k_{10} & 0 \\ 0 & 0 & 0 & -k_9-k_{10} & k_9+k_{10}+k_{11} & -k_{11} \\ 0 & 0 & 0 & 0 & -k_{11} & k_{11} \end{bmatrix}$$

$$\begin{Bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \end{Bmatrix} = \begin{bmatrix} f_0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \qquad (7)$$

Mode shapes

The equation of mode shape depended upon the matrixes of stiffness, the stiffness coefficient and determinate as [5-8]:

$$\Phi_{ij} = \frac{k_{ij}^{cT}}{|D|} F_o$$

$$[k_{ij}] = \begin{bmatrix} k_{11} & k_{12} & k_{13} & k_{14} & k_{15} & k_{16} \\ k_{21} & k_{22} & k_{23} & k_{24} & k_{25} & k_{26} \\ k_{31} & k_{32} & k_{33} & k_{34} & k_{35} & k_{36} \\ k_{41} & k_{42} & k_{43} & k_{44} & k_{45} & k_{46} \\ k_{51} & k_{52} & k_{53} & k_{54} & k_{55} & k_{56} \\ k_{61} & k_{62} & k_{63} & k_{64} & k_{65} & k_{66} \end{bmatrix} \quad (8)$$

The matrix stiffness coefficients

$$[k^c_{ij}] = \begin{bmatrix} k^{c}_{11} & k^{c}_{12} & k^{c}_{13} & k^{c}_{14} & k^{c}_{15} & k^{c}_{16} \\ k^{c}_{21} & k^{c}_{22} & k^{c}_{23} & k^{c}_{24} & k^{c}_{25} & k^{c}_{26} \\ k^{c}_{31} & k^{c}_{32} & k^{c}_{33} & k^{c}_{34} & k^{c}_{35} & k^{c}_{36} \\ k^{c}_{41} & k^{c}_{42} & k^{c}_{43} & k^{c}_{44} & k^{c}_{45} & k^{c}_{46} \\ k^{c}_{51} & k^{c}_{52} & k^{c}_{53} & k^{c}_{54} & k^{c}_{55} & k^{c}_{56} \\ k^{c}_{61} & k^{c}_{11} & k^{c}_{63} & k^{c}_{64} & k^{c}_{65} & k^{c}_{66} \end{bmatrix} \quad (9)$$

The cofactor transpose of the stiffness matrix

$$[k^c_{ij}]^T = \begin{bmatrix} k^{c}_{11} & k^{c}_{21} & k^{c}_{31} & k^{c}_{41} & k^{c}_{51} & k^{c}_{61} \\ k^{c}_{12} & k^{c}_{22} & k^{c}_{32} & k^{c}_{42} & k^{c}_{52} & k^{c}_{62} \\ k^{c}_{13} & k^{c}_{23} & k^{c}_{33} & k^{c}_{43} & k^{c}_{53} & k^{c}_{63} \\ k^{c}_{14} & k^{c}_{24} & k^{c}_{34} & k^{c}_{44} & k^{c}_{54} & k^{c}_{64} \\ k^{c}_{15} & k^{c}_{25} & k^{c}_{35} & k^{c}_{45} & k^{c}_{55} & k^{c}_{65} \\ k^{c}_{16} & k^{c}_{26} & k^{c}_{36} & k^{c}_{46} & k^{c}_{56} & k^{c}_{66} \end{bmatrix} \quad (10)$$

The Eigen vectors of the system are:

$\phi_{11}=\frac{[k_{11}^{c}]^{T}}{|D|}f_0$ $\phi_{12}=\frac{[k_{21}^{c}]^{T}}{|D|}f_0$ $\phi_{13}=\frac{[k_{31}^{c}]^{T}}{|D|}f_0$ $\phi_{14}=\frac{[k_{41}^{c}]^{T}}{|D|}f_0$

$\phi_{15}=\frac{[k_{51}^{c}]^{T}}{|D|}f_0$ $\phi_{16}=\frac{[k_{61}^{c}]^{T}}{|D|}f_0$ $\phi_{21}=\frac{[k_{21}^{c}]^{T}}{|D|}$ $\phi_{22}=\frac{[k_{22}^{c}]^{T}}{|D|}$

$\phi_{23}=\frac{[k_{32}^{c}]^{T}}{|D|}$ $\phi_{24}=\frac{[k_{42}^{c}]^{T}}{|D|}$ $\phi_{25}=\frac{[k_{52}^{c}]^{T}}{|D|}$ $\phi_{26}=\frac{[k_{62}^{c}]^{T}}{|D|}$

$\phi_{31}=\frac{[k_{13}^{c}]^{T}}{|D|}$ $\phi_{32}=\frac{[k_{23}^{c}]^{T}}{|D|}$ $\phi_{33}=\frac{[k_{33}^{c}]^{T}}{|D|}$ $\phi_{34}=\frac{[k_{43}^{c}]^{T}}{|D|}$

$\phi_{35}=\frac{[k_{53}^{c}]^{T}}{|D|}$ $\phi_{36}=\frac{[k_{63}^{c}]^{T}}{|D|}$ $\phi_{41}=\frac{[k_{14}^{c}]^{T}}{|D|}$ $\phi_{42}=\frac{[k_{24}^{c}]^{T}}{|D|}$

$\phi_{43}=\frac{[k_{34}^{c}]^{T}}{|D|}$ $\phi_{44}=\frac{[k_{44}^{c}]^{T}}{|D|}$ $\phi_{45}=\frac{[k_{54}^{c}]^{T}}{|D|}$ $\phi_{46}=\frac{[k_{64}^{c}]^{T}}{|D|}$

$\phi_{51}=\frac{[k_{15}^{c}]^{T}}{|D|}$ $\phi_{52}=\frac{[k_{25}^{c}]^{T}}{|D|}$ $\phi_{53}=\frac{[k_{35}^{c}]^{T}}{|D|}$ $\phi_{54}=\frac{[k_{45}^{c}]^{T}}{|D|}$

$\phi_{55}=\frac{[k_{55}^{c}]^{T}}{|D|}$ $\phi_{56}=\frac{[k_{65}^{c}]^{T}}{|D|}$ $\phi_{61}=\frac{[k_{16}^{c}]^{T}}{|D|}$ $\phi_{62}=\frac{[k_{26}^{c}]^{T}}{|D|}$

$\phi_{63}=\frac{[k_{36}^{c}]^{T}}{|D|}$ $\phi_{64}=\frac{[k_{46}^{c}]^{T}}{|D|}$ $\phi_{65}=\frac{[k_{56}^{c}]^{T}}{|D|}$ $\phi_{66}=\frac{[k_{66}^{c}]^{T}}{|D|}$ (11)

The modal matrix

$$\begin{bmatrix} \phi_{11} & \phi_{12} & \phi_{13} & \phi_{14} & \phi_{15} & \phi_{16} \\ \phi_{21} & \phi_{22} & \phi_{23} & \phi_{24} & \phi_{25} & \phi_{26} \\ \phi_{31} & \phi_{32} & \phi_{33} & \phi_{34} & \phi_{35} & \phi_{36} \\ \phi_{41} & \phi_{42} & \phi_{43} & \phi_{44} & \phi_{45} & \phi_{46} \\ \phi_{51} & \phi_{52} & \phi_{53} & \phi_{54} & \phi_{55} & \phi_{56} \\ \phi_{61} & \phi_{62} & \phi_{63} & \phi_{64} & \phi_{65} & \phi_{66} \end{bmatrix} \quad (12)$$

The determinate $|D|$ can be determined by using Fortran power station program.

The natural frequencies of the system

$$\omega_{ij} = \frac{[\phi_{ij}]^{T}[k][\phi_{ij}]}{[\phi_{ij}]^{T}[m][\phi_{ij}]}$$

Transpose of the mode shape:

$$[\phi_{ij}]^T = \begin{bmatrix} \phi_{11} & \phi_{21} & \phi_{31} & \phi_{41} & \phi_{51} & \phi_{61} \\ \phi_{12} & \phi_{22} & \phi_{32} & \phi_{42} & \phi_{52} & \phi_{62} \\ \phi_{13} & \phi_{23} & \phi_{33} & \phi_{43} & \phi_{53} & \phi_{63} \\ \phi_{14} & \phi_{24} & \phi_{34} & \phi_{44} & \phi_{54} & \phi_{64} \\ \phi_{15} & \phi_{25} & \phi_{35} & \phi_{45} & \phi_{55} & \phi_{65} \\ \phi_{16} & \phi_{26} & \phi_{36} & \phi_{46} & \phi_{56} & \phi_{66} \end{bmatrix} \quad (13)$$

The natural frequencies of the system are:

$$\omega_1 = \frac{[\phi_{11} \; \phi_{21} \; \phi_{31} \; \phi_{41} \; \phi_{51} \; \phi_{61}] \begin{bmatrix} k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11} \\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11} \\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11} \\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11} \\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11} \\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11} \end{bmatrix} \begin{bmatrix} \phi_{11} \\ \phi_{21} \\ \phi_{31} \\ \phi_{41} \\ \phi_{51} \\ \phi_{61} \end{bmatrix}}{[\phi_{11} \; \phi_{21} \; \phi_{31} \; \phi_{41} \; \phi_{51} \; \phi_{61}] \begin{bmatrix} m_1 & 0 & 0 & 0 & 0 & 0 \\ 0 & m_2 & 0 & 0 & 0 & 0 \\ 0 & 0 & m_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & m_4 & 0 & 0 \\ 0 & 0 & 0 & 0 & m_5 & 0 \\ 0 & 0 & 0 & 0 & 0 & m_6 \end{bmatrix} \begin{bmatrix} \phi_{11} \\ \phi_{21} \\ \phi_{31} \\ \phi_{41} \\ \phi_{51} \\ \phi_{61} \end{bmatrix}} \quad (14)$$

$$\omega_2 = \frac{[\phi_{12} \; \phi_{22} \; \phi_{32} \; \phi_{42} \; \phi_{52} \; \phi_{62}] \begin{bmatrix} k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11} \\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11} \\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11} \\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11} \\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11} \\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11} \end{bmatrix} \begin{bmatrix} \phi_{12} \\ \phi_{22} \\ \phi_{32} \\ \phi_{42} \\ \phi_{52} \\ \phi_{62} \end{bmatrix}}{[\phi_{12} \; \phi_{22} \; \phi_{32} \; \phi_{42} \; \phi_{52} \; \phi_{62}] \begin{bmatrix} m_1 & 0 & 0 & 0 & 0 & 0 \\ 0 & m_2 & 0 & 0 & 0 & 0 \\ 0 & 0 & m_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & m_4 & 0 & 0 \\ 0 & 0 & 0 & 0 & m_5 & 0 \\ 0 & 0 & 0 & 0 & 0 & m_6 \end{bmatrix} \begin{bmatrix} \phi_{12} \\ \phi_{22} \\ \phi_{32} \\ \phi_{42} \\ \phi_{52} \\ \phi_{62} \end{bmatrix}} \quad (15)$$

$$\omega_3 = \frac{[\phi_{13} \; \phi_{23} \; \phi_{33} \; \phi_{43} \; \phi_{53} \; \phi_{63}] \begin{bmatrix} k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11} \\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11} \\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11} \\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11} \\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11} \\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11} \end{bmatrix} \begin{bmatrix} \phi_{13} \\ \phi_{23} \\ \phi_{33} \\ \phi_{43} \\ \phi_{53} \\ \phi_{63} \end{bmatrix}}{[\phi_{13} \; \phi_{23} \; \phi_{33} \; \phi_{43} \; \phi_{53} \; \phi_{63}] \begin{bmatrix} m_1 & 0 & 0 & 0 & 0 & 0 \\ 0 & m_2 & 0 & 0 & 0 & 0 \\ 0 & 0 & m_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & m_4 & 0 & 0 \\ 0 & 0 & 0 & 0 & m_5 & 0 \\ 0 & 0 & 0 & 0 & 0 & m_6 \end{bmatrix} \begin{bmatrix} \phi_{13} \\ \phi_{23} \\ \phi_{33} \\ \phi_{43} \\ \phi_{53} \\ \phi_{63} \end{bmatrix}} \quad (16)$$

$$\omega_4 = \frac{\begin{bmatrix}\phi_{14} & \phi_{24} & \phi_{34} & \phi_{44} & \phi_{54} & \phi_{64}\end{bmatrix}\begin{bmatrix}k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11}\\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11}\\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11}\\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11}\\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11}\\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11}\end{bmatrix}\begin{bmatrix}\phi_{14}\\ \phi_{24}\\ \phi_{34}\\ \phi_{44}\\ \phi_{54}\\ \phi_{64}\end{bmatrix}}{\begin{bmatrix}\phi_{14} & \phi_{24} & \phi_{34} & \phi_{44} & \phi_{54} & \phi_{64}\end{bmatrix}\begin{bmatrix}m_1 & 0 & 0 & 0 & 0 & 0\\ 0 & m_2 & 0 & 0 & 0 & 0\\ 0 & 0 & m_3 & 0 & 0 & 0\\ 0 & 0 & 0 & m_4 & 0 & 0\\ 0 & 0 & 0 & 0 & m_5 & 0\\ 0 & 0 & 0 & 0 & 0 & m_6\end{bmatrix}\begin{bmatrix}\phi_{14}\\ \phi_{24}\\ \phi_{34}\\ \phi_{44}\\ \phi_{54}\\ \phi_{64}\end{bmatrix}} \quad (17)$$

$$\omega_5 = \frac{\begin{bmatrix}\phi_{15} & \phi_{25} & \phi_{35} & \phi_{45} & \phi_{55} & \phi_{65}\end{bmatrix}\begin{bmatrix}k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11}\\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11}\\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11}\\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11}\\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11}\\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11}\end{bmatrix}\begin{bmatrix}\phi_{15}\\ \phi_{25}\\ \phi_{35}\\ \phi_{45}\\ \phi_{55}\\ \phi_{65}\end{bmatrix}}{\begin{bmatrix}\phi_{15} & \phi_{25} & \phi_{35} & \phi_{45} & \phi_{55} & \phi_{65}\end{bmatrix}\begin{bmatrix}m_1 & 0 & 0 & 0 & 0 & 0\\ 0 & m_2 & 0 & 0 & 0 & 0\\ 0 & 0 & m_3 & 0 & 0 & 0\\ 0 & 0 & 0 & m_4 & 0 & 0\\ 0 & 0 & 0 & 0 & m_5 & 0\\ 0 & 0 & 0 & 0 & 0 & m_6\end{bmatrix}\begin{bmatrix}\phi_{15}\\ \phi_{25}\\ \phi_{35}\\ \phi_{45}\\ \phi_{55}\\ \phi_{65}\end{bmatrix}} \quad (18)$$

$$\omega_6 = \frac{\begin{bmatrix}\phi_{16} & \phi_{26} & \phi_{36} & \phi_{46} & \phi_{56} & \phi_{66}\end{bmatrix}\begin{bmatrix}k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11}\\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11}\\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11}\\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11}\\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11}\\ k_{11} & k_{11} & k_{11} & k_{11} & k_{11} & k_{11}\end{bmatrix}\begin{bmatrix}\phi_{16}\\ \phi_{26}\\ \phi_{36}\\ \phi_{46}\\ \phi_{56}\\ \phi_{66}\end{bmatrix}}{\begin{bmatrix}\phi_{16} & \phi_{26} & \phi_{36} & \phi_{46} & \phi_{56} & \phi_{66}\end{bmatrix}\begin{bmatrix}m_1 & 0 & 0 & 0 & 0 & 0\\ 0 & m_2 & 0 & 0 & 0 & 0\\ 0 & 0 & m_3 & 0 & 0 & 0\\ 0 & 0 & 0 & m_4 & 0 & 0\\ 0 & 0 & 0 & 0 & m_5 & 0\\ 0 & 0 & 0 & 0 & 0 & m_6\end{bmatrix}\begin{bmatrix}\phi_{16}\\ \phi_{26}\\ \phi_{36}\\ \phi_{46}\\ \phi_{56}\\ \phi_{66}\end{bmatrix}} \quad (19)$$

Generalized response for the system

For general n-degree of freedom system with mass m_i, stiffness matrix k_i, and damping c_i the response in each mode are:

$$x_i(t) = \sum_{i=1}^{6}\sum_{j=1}^{6} A_i \phi_{ij} \sin(\omega_j t + \psi_j)$$

The system responses are:

$x_1(t) = A_1\phi_{11}\sin(\omega_1 t+\psi_1) + A_2\phi_{12}\sin(\omega_2 t+\psi_2) + A_3\phi_{13}\sin(\omega_3 t+\psi_3) + A_4\phi_{14}\sin(\omega_4 t+\psi_4) + A_5\phi_{15}\sin(\omega_5 t+\psi_5) + A_6\phi_{16}\sin(\omega_6 t+\psi_6)$ (20)

$x_2(t) = A_1\phi_{21}\sin(\omega_1 t+\psi_1) + A_2\phi_{22}\sin(\omega_2 t+\psi_2) + A_3\phi_{23}\sin(\omega_3 t+\psi_3) + A_4\phi_{24}\sin(\omega_4 t+\psi_4) + A_5\phi_{25}\sin(\omega_5 t+\psi_5) + A_6\phi_{26}\sin(\omega_6 t+\psi_6)$ (21)

x_3 (t)= $A_1\phi_{31}$ sin ($\omega_1 t+\psi_1$)+ $A_2\phi_{32}$ sin ($\omega_2 t+\psi_2$)+ $A_3\phi_{33}$ sin ($\omega_3 t+\psi_3$) + $A_4\phi_{34}$ sin ($\omega_4 t+\psi_4$)+ $A_5\phi_{35}$ sin($\omega_5 t+\psi_5$)+ $A_6\phi_{36}$ sin ($\omega_6 t+\psi_6$) (22)

x_4(t)= $A_1\phi_{41}$ sin ($\omega_1 t+\psi_1$)+ $A_2\phi_{42}$ sin ($\omega_2 t+\psi_2$)+ $A_3\phi_{43}$ sin ($\omega_3 t+\psi_3$) + $A_4\phi_{44}$ sin ($\omega_4 t+\psi_4$)+ $A_5\phi_{45}$sin ($\omega_5 t+\psi_5$)+ $A_6\phi_{46}$ sin ($\omega_6 t+\psi_6$) (23)

x_5 (t)= $A_1\phi_{51}$ sin ($\omega_1 t+\psi_1$)+ $A_2\phi_{52}$ sin ($\omega_2 t+\psi_2$)+ $A_3\phi_{53}$ sin ($\omega_3 t+\psi_3$) + $A_4\phi_{54}$ sin ($\omega_4 t+\psi_4$)+ $A_5\phi_{55}$ ($\omega_5 t+\psi_5$)+ $A_6\phi_{56}$ sin ($\omega_6 t+\psi_6$) (24)

x_6(t)= $A_1\phi_{61}$ sin ($\omega_1 t+\psi_1$)+ $A_2\phi_{62}$ sin ($\omega_2 t+\psi_2$)+ $A_3\phi_{63}$ sin ($\omega_3 t+\psi_3$) + $A_4\phi_{64}$ sin ($\omega_4 t+\psi_4$)+ $A_5\phi_{65}$sin ($\omega_5 t+\psi_5$)+ $A_6\phi_{66}$ sin ($\omega_6 t+\psi_6$) (25)

The system velocities are:

$$\dot{x}_i(\mathrm{t}) = \sum_{\mathrm{i}=1}^{6}\sum_{\mathrm{j}=1}^{6} \omega_{\mathrm{j}} A_i \phi_{ij} \sin(\omega_{\mathrm{j}}\mathrm{t} + \psi_{\mathrm{j}})$$

$\dot{x}_6$(t)=ω_1 $A_1\phi_{61}$cos ($\omega_1 t+\psi_1$)+ω_2 $A_2\phi_{62}$cos ($\omega_2 t+\psi_2$)+ω_3 $A_3\phi_{63}$cos ($\omega_3 t+\psi_3$) +ω_4 $A_4\phi_{64}$cos ($\omega_4 t+\psi_4$)+ω_5 $A_5\phi_{65}$cos ($\omega_5 t+\psi_5$)+ω_6 $A_6\phi_{66}$cos ($\omega_6 t+\psi_6$) (26)

$\dot{x}_5$(t)=ω_1 $A_1\phi_{51}$cos ($\omega_1 t+\psi_1$)+ω_2 $A_2\phi_{52}$cos ($\omega_2 t+\psi_2$)+ω_3 $A_3\phi_{53}$cos ($\omega_3 t+\psi_3$) +ω_4 $A_4\phi_{54}$cos ($\omega_4 t+\psi_4$)+ω_5 $A_5\phi_{55}$cos ($\omega_5 t+\psi_5$)+ω_5 $A_6\phi_{55}$cos ($\omega_6 t+\psi_6$) (27)

$\dot{x}_4$(t)=ω_1 $A_1\phi_{41}$cos ($\omega_1 t+\psi_1$)+ω_2 $A_2\phi_{42}$cos ($\omega_2 t+\psi_2$)+ω_3 $A_3\phi_{43}$cos ($\omega_3 t+\psi_3$) +ω_4 $A_4\phi_{44}$cos ($\omega_4 t+\psi_4$)+ω_5 $A_5\phi_{45}$cos ($\omega_5 t+\psi_5$)+ω_6 $A_6\phi_{46}$cos ($\omega_6 t+\psi_6$) (28)

$\dot{x}_3$(t)=ω_1 $A_1\phi_{31}$cos ($\omega_1 t+\psi_1$)+ω_2 $A_2\phi_{32}$cos ($\omega_2 t+\psi_2$)+ω_3 $A_3\phi_{33}$cos ($\omega_3 t+\psi_3$) +ω_4 $A_4\phi_{34}$cos ($\omega_4 t+\psi_4$)+ω_5 $A_5\phi_{35}$cos ($\omega_5 t+\psi_5$)+ω_6 $A_6\phi_{36}$cos ($\omega_6 t+\psi_6$) (29)

$\dot{x}_2$(t)=ω_1 $A_1\phi_{21}$cos ($\omega_1 t+\psi_1$)+ω_2 $A_2\phi_{22}$cos ($\omega_2 t+\psi_2$)+ω_3 $A_3\phi_{23}$cos ($\omega_3 t+\psi_3$) +ω_4 $A_4\phi_{24}$cos ($\omega_4 t+\psi_4$)+ω_5 $A_5\phi_{25}$cos ($\omega_5 t+\psi_5$)+ω_6 $A_6\phi_{26}$cos ($\omega_6 t+\psi_6$) (30)

$\dot{x}_1$(t)=ω_1 $A_1\phi_{11}$cos ($\omega_1 t+\psi_1$)+ω_2 $A_2\phi_{12}$cos ($\omega_2 t+\psi_2$)+ω_3 $A_3\phi_{13}$cos ($\omega_3 t+\psi_3$) +ω_4 $A_4\phi_{14}$cos ($\omega_4 t+\psi_4$)+ω_5 $A_5\phi_{15}$cos ($\omega_5 t+\psi_5$)+ω_6 $A_6\phi_{16}$cos ($\omega_6 t+\psi_6$) (31)

3. Results and discussion

One could see that as predicted by physical inspections, constraining the boundaries results in increments of the amplitudes .It may seem that natural condition of the hand-arm are most closely described as single degree of freedom system. From a modal analysis point of view, modeling of hand-arm and hand arm tool vibration are two challenging problems and they might have no unique answer especially in terms of classic boundary condition or what seems to be logically valid. For the identification of correct analysis is to do theoretical investigation and compare the results with model frequencies and shapes and to identify which set boundary conditions best describes the problem. Thus ,values of natural frequencies and the shape of natural modes are necessary for the jackhammer Model Updating of the hand .These values are important in three other senses .First ,these natural frequencies along with natural modes ,which are presented here, could be used for the development of lumped – parameter models of the hand –arm vibration .The procedure is one of the model analysis inverse problems domains .These models are typically easier to deal with and at the same time they could be integrated with other existing lumped-parameter models of the system. It is especially more important known that most of the vibrational models of the system are lumped-parameter models. Second, these values could be used for the determination of the type of vibrational loading that the hand-arm is exposed to and to determine if these vibrational risks could result in cumulative of the amplitudes situation of the system .Third, these values are of importance and change of values could be regarded as a case of probable hand-arm injuries. Forther the papers are presented acomplete analysis of the system in single and combined modes of boundary condition are necessary to be in hand-arm vibration injuries especially in the cases of large amplitude deficiency. Effects of geometry on natural frequencies of the humerus are of special interest mainly because of the fact that one could expect the range of natural frequencies of a humerus. Knowing how the vibrational properties are affected by geometry calls for a huge number of computational investigations among which the most important ones are presented here and some are mitted due to constraints .The natural frequencies are affected by the hand of individual human samples being considered. theoretical concerned with the hand arm vibration indicate that the design of jack hammer can be improved by predicting the hand-arm jack hammer behavior using the simulation .the simulation figures are being performed. First, simulation assumes that the humerus is subject to change in different amplitudes without dynamic vibration absorber. Second simulation, assumed that the humerus is subject to change in different amplitudes with dynamic vibration absorber. Qualitatively, in both simulations natural frequencies are being decreased by using dynamic vibration absorber of the geometrical dimensions. Values of the first simulation are presented here;could be consulted for computed values of the second simulation.The original geometry dimension are being considered.

4. System vibration control

By dividing the jack hammer system into discrete masses as shown in Fig.(3); m_1=10kg ,$m_{2,3}$=5kg ,m_4=15kg,m_5=5kg,m_6 which represent to the mass of hand arm of the worker=(4.5Kg).determining the six responses of the jack hammer system by one can add the dynamic vibration absorber between the masses(1,2,and3). The dynamic vibration absorber is as a simply single degree of freedom system ,usually used in the form of a simply spring – mass system .When it added to another single degree of freedom system as an auxiliary system ,it will transform the hole system in two degree of freedom with two natural frequencies of vibration .One of the natural frequencies is set above the excitation frequency while the other is set below it ,so that the main mass of entire system will have very small amplitude of vibration instead of very large amplitude under the given excitation. Then we can see how the response by adding the dynamic vibration absorber which will make the amplitude of response that reaches to the Hand-Arm very small .This reduces the risks, and protect the workers.

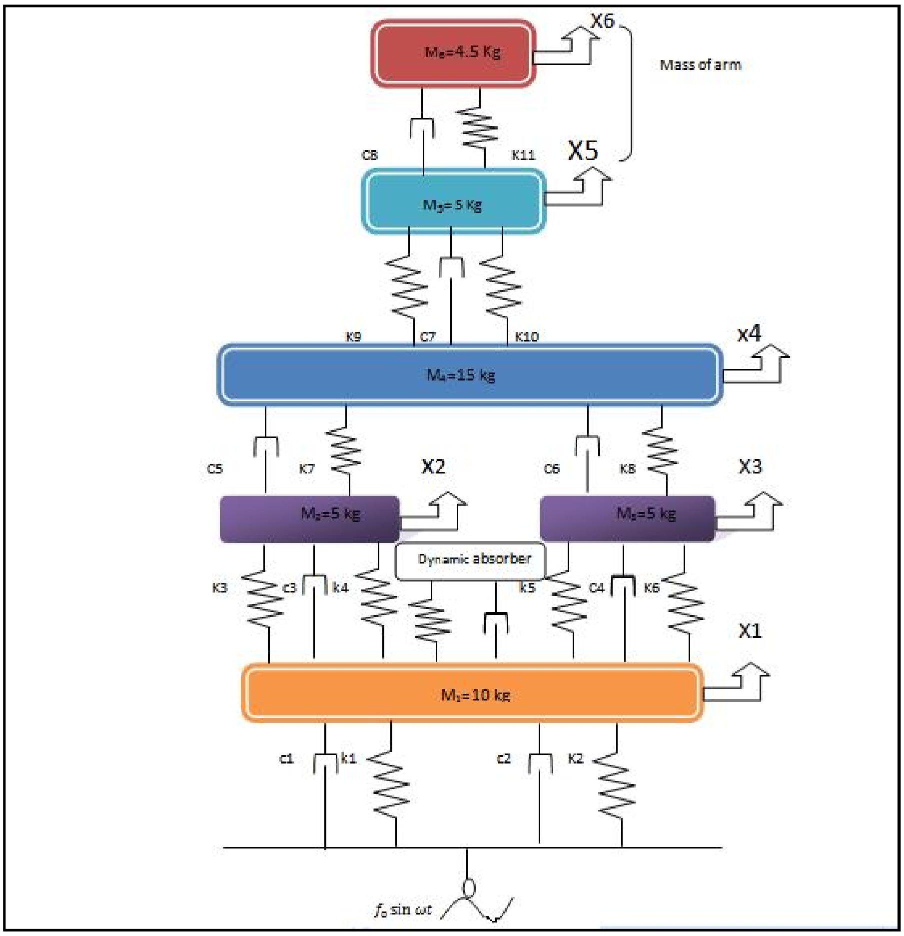


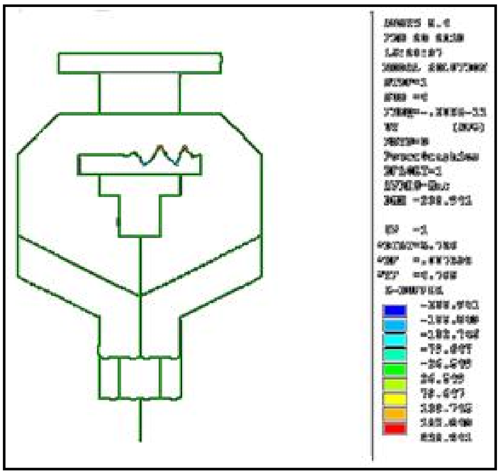
Figure (3). Systematic representation with dynamic absorber.

5. The deformations in jack hammer geometry

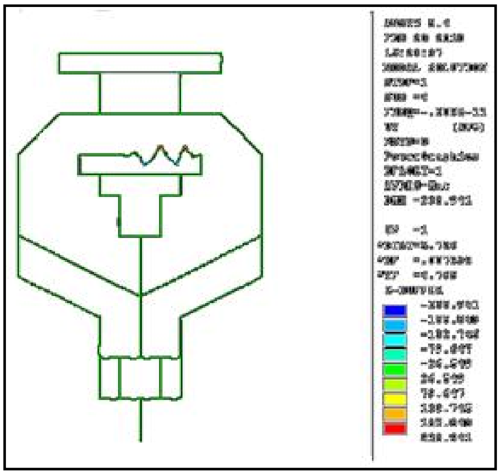
The vibration tool" jack hammer" can be drawn in Ansys v(5.4) program by putting the key point in the worksheet and connect it by lines then putting the force in the lower point (that means forced vibration)which its value will be between (10-20)N. After that it becomes easy to carry out the program and we will see how the deformation will be clear in the truss of the jack hammer due to the higher amplitude of response and how this deformation would reach the hand in high amplitude.

The uses of Ansys in this projects are to understand how the high amplitude of response will reach to the arm of the worker and causes the damage of the hand.

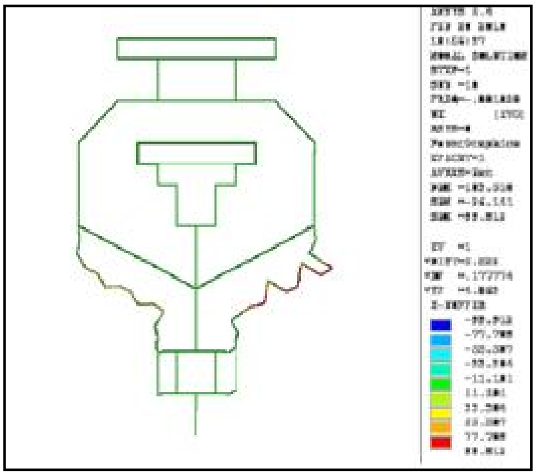
Figures (4-13) show the deformation which happened to the geometry due to the excitation in different masses ,and the red color shows the highest stress that affect the device ,and the other colors will be the decreasing of stresses gradually.



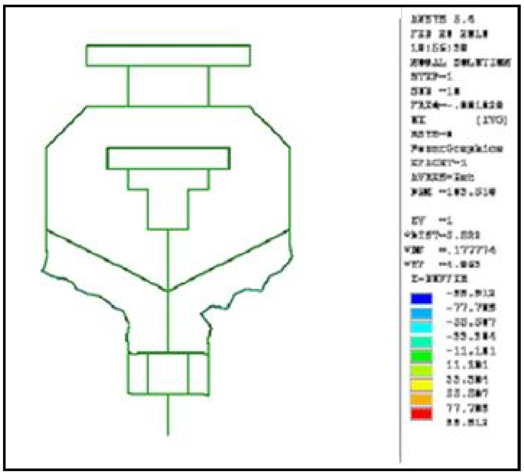
Figure(4). First mode shape .



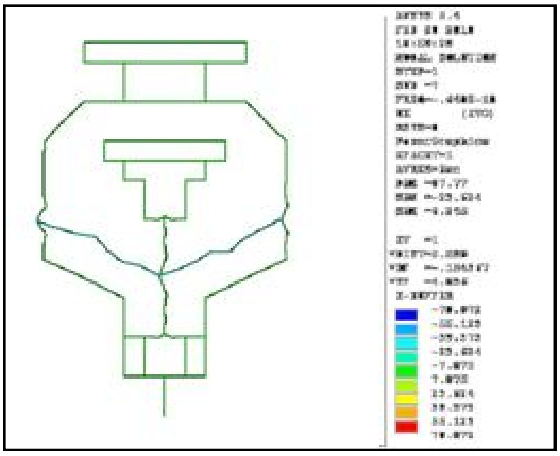
Figure(5). First mode shape.



Figure(6).Second mode shape.



Figure(7). Third mode shape.



Figure(8).Forth mode shape .

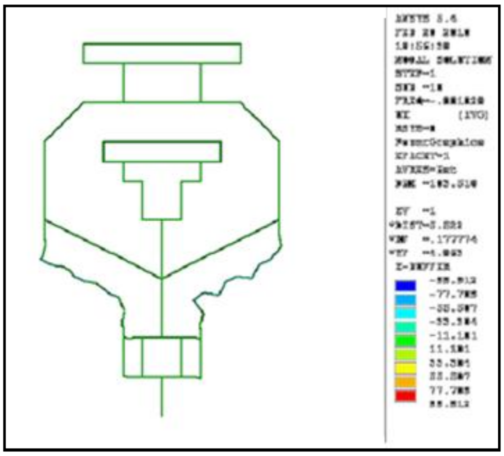


Figure (9).Fifth mode shape .

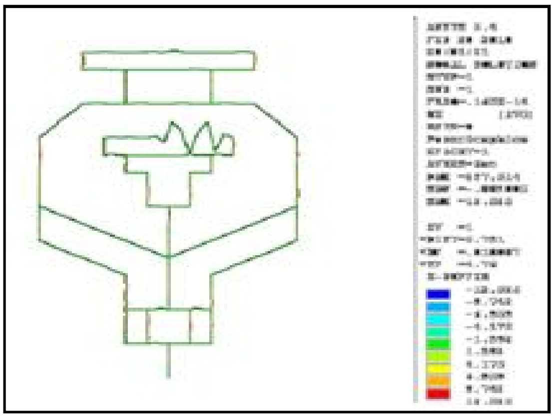


Figure (10).Sixth mode shape .

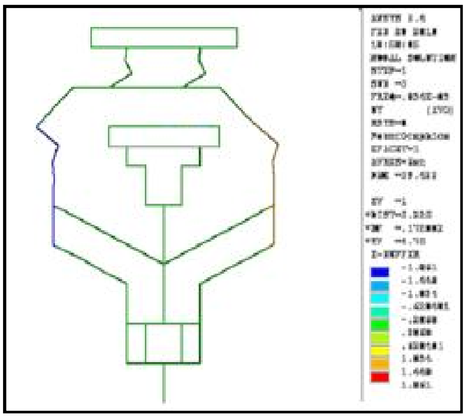


Figure (11).Seventh mode shape.

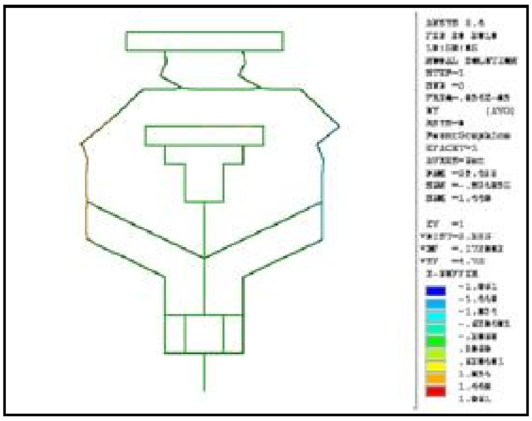


Figure (12).Eighth mode shape .

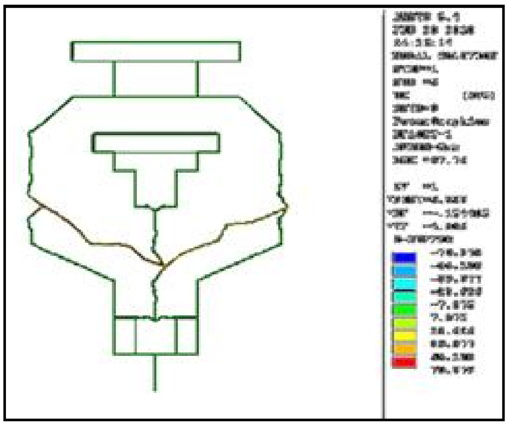


Figure (13). Ninth mode shape.

Figure (14) shows the responses of the system . The six equations of response which have 12 unknown like (A,B,C,D,E,F)and the six phase angle now can find the velocity of every response ,and by finding it there are 12 varabile and 12 equations . By using Fortran power station one can find the data that used a program to draw the curves for all responses Figure (14).

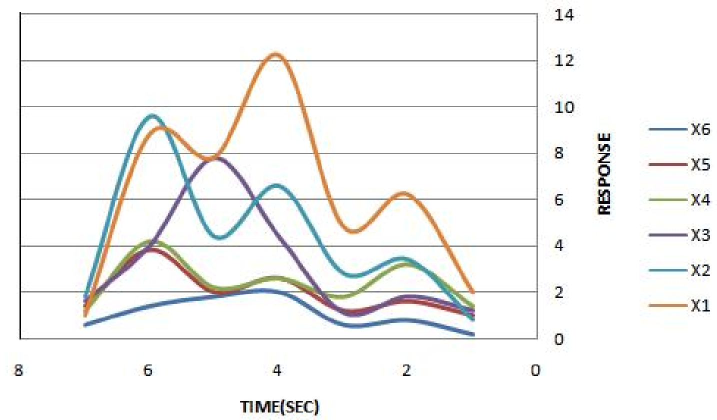
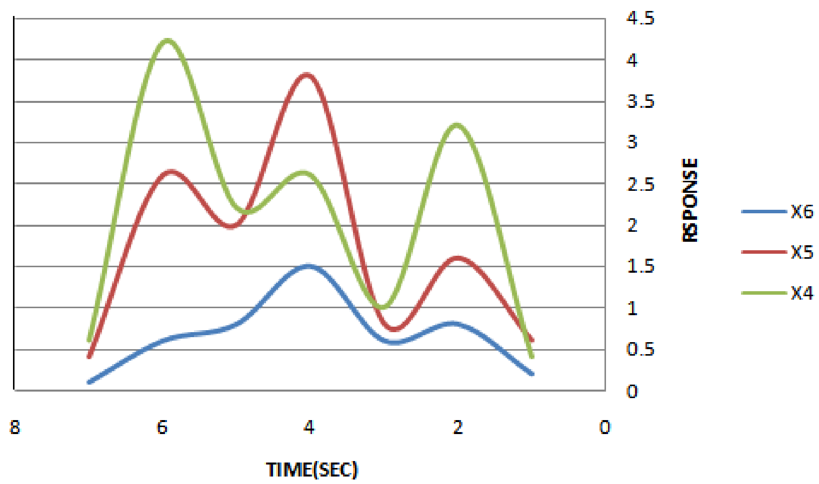


Figure (14). System responses without dynamic vibration absorber.

By adding the dynamic vibration absorber between the masses (1, 2, 3) this will vanish the response of these masses as shown in Figure(15). This response of (4, 5, 6) will also reduced to be safer for the arm.



Figure(15) .System responses with dynamic vibration absorber.

The difference between the two Figures (14) and (15) shows that the dynamic vibration absorber will reduce the very large amplitude and the response that reaches to the arm will be less in the presence of dynamic vibration absorber ,and this will make the vibration reached to the arm less so that the risks will be reduced .

7. Conclusions

The jack hammer was of the hand-operated type in common use. Accelerations caused by it were taken as a point of reference since most persons have heard, if not seen, this type of machine in operation. These particular ground accelerations were the most periodic of any obtained in this investigation. The distance from the source was measured from the point of application of the bit.

Most papers on the investigation of the dynamics of jackhammer system it is usually assumed that during the operating process the parameters of these systems remain constant. However, the parameters, especially the stiffness and damping coefficients under impact. Therefore a study of jackhammer systems under conditions close to the actual ones leads to the problem of investigating dynamic systems in the presence of randomly varying parameters.

The simulation proves the presented mathematical model in terms of more accurate model parameters and analyzes the dynamic characteristics of the jackhammer structure when it is subjected to vibrational loading, studies the propagation taking into account the response vector (elements representing the response in each DOF), the excitation vector (elements representing the force in each DOF), degree of freedom (points & directions), frequency response matrix, and frequency response function.

Based on the optimal parameters, we design dynamic vibration absorber (spring – dashpot system) whose stiffness and damping are independently adjustable, to reduce the propagation of amplitudes to the desired value by decreasing the high amplitudes to very small amplitudes to protect the operator from the hand vibration risks.Hand Arm Vibration will often affect the people who regularly use high vibration equipment such as a jack hammer tool .The vibration of the tool or any material being vibrated is transmitted to the hands. Regular and frequent exposure to hand-arm vibration can lead to permanent health effects. This is most likely when contact with a vibrating tool or work process is regular part of a person's job. Occasional exposure is unlikely to cause ill health , the exposure limit value is the maximum amount of vibration an employee may be exposed to on any single day. For hand-arm vibration the exposure limit value is a dailexposure of 5 m/s^2 It represents a high risk above which employees should not be exposed. The degree of risk will depend on many factors such as the amount of vibration, how long the tools are used for, the working posture and how cold it is will all make a difference. Using ansys programs version (5.4) will help us to predict the eigenvectors (mode shapes) and the natural frequency of jack hammer..the main aim of this research was to reduce the high amount of vibration and this can be done by using the dynamic vibration absorber which is a simply-spring mass system (single degree of freedom system) added to the original mass system to transform the system to degree of freedom system and the entire system will have two eigenvalue one above the excitation and the other under the excitation .And this will protect the employees from the risk and it is clear how amplitude of response is different after adding dynamic vibration absorber.

8. References

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9. Nomenclature

Symbols	**Description**	**Unit**
A ,B ,C, D ,E ,F	Variables	---
C	Damping matrix	[N.s/m]
F_0	Force applied to the system	[N]
K	Stiffness matrix	[N/m]
$[k^c]$	Cofactor of the stiffness matrix.	[N/m]
$[k^c]^T$	Cofactor transpose of the stiffness matrix.	[m / N]
ϕ_{ij}	Mode shape (eigenvectors)	---
$[\phi_{ij}]^T$	Transpose of the mode shape matrix	---
$\|D\|$	Determinate of stiffness matrix.	---
ω	Natural frequency	[rad/sec]
ψ	Phase angle	---
M	Mass	[Kg]
$x(t)$	Response of the system	[mm]
$\dot{x}(t)$	Velocity	[mm/s]
$\ddot{x}(t)$	Acceleration	[mm/s^2]