FIFTH INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
DECEMBER 15-18, 1997
ADELAIDE, SOUTH AUSTRALIA

# ACOUSTICAL PROPERTIES OF FERROUS METAL WITH ONE AND TWO ALLOYING ELEMENTS

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## ABSTRACT

In the analytical and experimental work reported in this paper, sound radiation of the rectangular plates made from iron-chrome (**Fe-Cr**) and iron-chrome-manganese (**Fe-Cr-Mn**) alloys have been studied in some details. The analysis of the experimental data indicated that the change of the chemical composition and corresponding alloys structural changes affected the attenuation rate of the sound radiated by the plates. High rates of sound attenuation have been recorded for the ferrous alloy with 18% **Cr** and 12% of **Mn**.

## INTRODUCTION

Despite the wide use of a plastic and composite material for a machine structural components, metal still makes up a large portion of the average machine, especially in drivetrains, valvetrains and where combination of high strength at both "normal" and elevated temperatures are required.

When a structure or machine component is acted on by a fluctuating force, whether this force be harmonic, impulsive or random with respect to time, some or all components will vibrate and radiate sound. Attention has recently been drawn to the importance of impulsive noise, especially from metal-to-metal collisions. Considerable impulsive noise is generated

by dynamic contact of machine elements (gears, balls or rolls in bearings, etc.). The high intensity forces developed in the clearances due to backlash result in short duration impacts which create vibration and intensive sound radiation.
Analysis of sound radiation from solid bodies appears in works Morse and Ingard, 1968, [2], of Skudrzyk, 1971, [1], Cremer and Heckl, 1973, [3]. Further studies of this problem were conducted by Koss and Alfredson, 1974, [4], Dreiman, 1979, [5], Endo, 1981, [6].
A survey of the literature shows that the sound radiation efficiency of vibrating bodies depends upon geometry, external static and dynamic loads, boundary conditions, surrounding medium, and properties of the metal. As show investigations, significant variations in metal properties, which can affect sound, do occur if we will change the chemical composition of the metal, heat treatment or the manufacturing process.

## FORMULATION OF THE PROBLEM

Theoretical development of impact is concerned very often with the transfer of mechanical energy through a structure and neglects the impulsive sound produced during the collision itself. This omission is usually justified since only a small fraction of the mechanical impact energy is radiated during impact. However, the form of the impact-force history has an important effect on the quantity and spectral content of the sound energy radiated after the impact. The disturbance generated by contact propagates into the structure with finite velocity. Its subsequent reflections from the bounding surfaces then produce vibrations within the structure. It has been shown in Ref. [7] that the ratio of vibrational energy $e$ to the initial kinetic energy $e_0$ of impact is very small, approximately

$$e / e_0 = (1/50)\cdot(V_0 / C_0) \qquad (1)$$

where $V_0$ is the relative velocity of impact and $C_0$ is the dilational wave velocity. For most practical examples of colliding solids, although the ratio is considerably less than unit, this free elastic vibrational energy is responsible for most of the sound radiation associated with the structure. The sound radiation characteristics of a solid may be described in terms of the radiation efficiency, power conversion efficiency, which is defined as the ratio of the power radiated into a medium to the vibratory power supplied to the solid, and in terms of the radiation loss factor which indicates the extent to which the vibration of a system are damped due to the radiation of power from the solid to the ambient medium [3]. Sound radiation efficiency of a solid may also be characterized by attenuation rate $d$ of the sound when the excitation of the system is removed, so that energy is no longer supplied to the system. In this case the rate of change in the sound pressure level per unit of time will be $d = \Delta L / t + B$ dB / s, where $\Delta L$ is change in sound level in db, $t$ is time in seconds, and $B$ is a constant accounting for losses due to environmental scattering, transmission to neighboring elements and absorption at interfaces. Consider a system that vibrates at the circular frequency $\omega$ and which at time $t = 0$ has a reversible mechanical energy $E_1$. If the system is disconnected from all external sources, part of this energy is changed into heat and reversible energy $E_2$ that is left in the system at this time:

$$E_2 = E_1 \cdot e_n^{-\eta\omega t} \qquad (2)$$

where $\eta$ is loss factor. It is evident from Eq. ( 2 ) that energy decay may be described by the function $e_n^{-\eta\omega t}$. In practice one can measure the reverberation time within which the energy of the vibration is reduced to the one millionth of its initial value and determine the loss factor from the relation

$$\eta = \ln 10^6 / f_n \cdot t_{60} \qquad (3)$$

The very important source of loss factor is damping of the structure. Principally, the source of damping are the internal friction $\Theta^{-1}$ of the metal, external (Columb) friction due to interfacial slip at joints, hydrodynamic (viscous) damping. When a solid vibrates in a gaseous medium and mechanical interfaces are eliminated, the predominating component causing the loss at audio-frequencies is internal friction $\Theta^{-1}$.
Thus, a duration of the sound radiation is equal to the reverberation time

$$t_{60} = 2.199 / f_n \cdot \Theta^{-1} \qquad (4)$$

Elastic vibration and consequently sound radiation result from the collision and rubbing of components of a mechanical system joined in kinematic pairs. The dynamic response of the system components to impact-type forces can be considered as forced (acceleration noise) and free vibration (ringing noise). The sudden motion of the end surfaces during contact produces a sound pulse followed by the ringing noise. Duration of this sound pulse is equal to the impact force duration $\tau$, and total duration of sound radiation from a vibrating component is equal to the sum of forced and free vibration time. Sound radiation due to the free vibration of the component following impact is very often dominant.
In many analytical and experimental works the dynamic analysis of collision and its associated acoustic radiation was based on a scheme suggested by Hertz. However, strict application of the Hertz law to the causes of contact of metallic bodies is very often limited. Some efforts have been made to use another relation applicable for plastic contact indentation taking place during metal-to-metal impact. The simplest and most successful static relation known as the Mayer law may be described by the relation [7]:

$$F = \pi \cdot \sigma_0 \cdot a^2 = 2 \cdot \pi \cdot \sigma_0 \cdot r_s \cdot \alpha = m_s \, (d^2 \alpha / dt^2)$$

OR

$$d^2 \alpha / dt^2 + 2 \cdot \pi \cdot \sigma_0 \cdot r_s \cdot \alpha / m_s = 0 \qquad (5)$$

where **F** is the applied load, **a** is the contact diameter, $m_s$ is the mass of the sphere $r_s$ is the radius of the sphere, $\sigma_0$ is the yield stress, and $\alpha$ is a compression. The maximum compression occurs at the time

$$\tau = \pi / 2 \ (2\pi r_s \sigma_0)^{1/2}, \mathrm{s} \qquad (6)$$

which represents the entire duration of the contact. For plates thin relative to their lateral dimension and deformed to only small curvatures under impact load, an approximate theory has been developed corresponding to the simple one-dimensional behavior of the beam. The natural frequency of the plate with free edges boundary conditions can be expressed as

$$f_{m1n} = C_0^2 / 2\pi \, [ Eh^3 / 12m_p (1 - \mu^2) ]^{1/2} [ (m/\alpha_1)^2 + (n/\beta)^2 ] \qquad (7)$$

where **E** is elastic modulus, $\mu$ is Poisson's ratio, $C_0$ is speed of sound, $m_p$ mass of the plate, **(m)** and **(n)** is the mode number, **h** is the thickness of the plate, ( $\alpha_1$ ) and ( $\beta$ ) are linear dimensions of the plate. Taking into account sound radiation time ( $t_{60} - \tau$ ), and natural frequency of the plate, we can estimate the attenuation rate of sound radiation for rectangular metal plate from the following equation:

$$d = \frac{60 \, [ (m/\alpha_1)^2 + (n/\beta)^2 ] \, \Theta^{-1} \, (\sigma_0 E h^3 r_s)^{1/2}}{4.85 \, [\sigma_0 (1 - \mu^2) m_p \rho r_s]^{1/2} - 0.35 \, [ (m/\alpha_1)^2 + (n/\beta)^2 ] \, \Theta^{-1} (\pi E h^3 m_s)^{1/2}} \qquad (8)$$

where $\rho$ is the metal density. The attenuation rate of sound radiation has been shown to be affected by the geometrical parameters of the plate, physical and mechanical properties of the metal.

Alloying elements are incorporated in metal to improve physical and mechanical properties, to increase resistance to chemical attack, to influence other special properties such as magnetic permeability, neutron absorption, resistant to the continuous heat, etc. It is important for the noise control and nondestructive diagnostics purposes to study the effect of the microstructural changes as well as physical and mechanical properties of the metal on its sound radiation parameters.

## DATA ANALYSIS AND DISCUSSION

A rectangular plate 50x50x4 mm in size made from iron-chrome and iron-manganese alloys have been tested in anechoic chamber. The chemical composition of the specimens are shown in Table 1. During the test, the samples were horizontally suspended by thin steel cables to reduce losses of the vibration energy at contact points. Sound radiation was induced by the impact of the steel sphere 10mm dia. (4.5 g) on the center of the plate. The position of the specimens and drop height H of the steel sphere were kept identical throughout the tests, hence the impact velocity ($V_0 = 2gH$) and amplitude were assumed to have remained constant. The Hewlett-Packard Structural Dynamic Analyzer 5423A has been used for the data collection and analysis.

## *IRON-CHROME ALLOYS*

Sensitivity of the physical and mechanical properties of the metals to the metal structure changes [8] indicates that the phase composition will affect the radiated sound.
Figure 1 shows the attenuation rate of sound (1), duration of the ringing sound (2) radiated by plate, change of the internal friction $\Theta^{-1}$ (3) , and phase boundaries of the **Fe-Cr** alloys with increase of chrome content.
The sound attenuation rate changed in the limits 23 dB/s to 90 dB/s with increase of the chrome content in the alloys. The sound attenuation rate of the alloys with up to 0.85%Cr is not more than 21 dB/s. When the percentage of chromium rises up to 20% **Cr** the carbides in the alloys remain in the martensitic form, which means that the alloys are permanently hard and brittle. The sound attenuation rises and reaches the maximum (90 dB/s) for the alloy with 18.99% **Cr** located on the boundary of single ( $\alpha$ - **Fe** ) phase and two- phase ( $\alpha$ - **Fe** + $\sigma$ ) region of the structural diagram. The sound attenuation rate changed in the range 30 dB/s to 45 dB/s for the alloys with more than 21% **Cr**.

## *IRON-CHROME-MANGANESE ALLOYS*

The spectra of sound radiation for samples #70 (10.48% **Mn**, 14.9% **Cr**), #71 (10.65% **Mn**, 17.8% **Cr**) are illustrated in Figure 2. In alloys with 10% **Mn** to 14%**Mn** the transformation of single ( $\alpha$ - **Fe** ) phase into ( $\alpha$ -**Fe** + $\gamma$ ) phase and metastable $\xi$ phase of the structure is accompanied by an increase in the strength of the **Fe-Cr-Mn** alloys.
The recorded 82 dB/s attenuation rate for the alloys located in ( $\alpha + \gamma + \sigma$ ) phase region of the structural diagram is due to the fact that the structural transformation occurring in **Fe-Cr-Mn** alloys rich in iron have a substantial influence on the metal physical properties. Reduced sound pressure levels in high frequency region of the spectra can be explained by these changes., especially by increase of the internal friction $\Theta^{-1}$ and hardness of the alloys.

## CONCLUSIONS

1. The attenuation of the sound radiated by the metal has been shown to be affected by the geometric dimensions of the sound radiation sample, physical and mechanical properties of the metal. The physical and mechanical properties can be modified by controlling the chemical composition, heat treatment and mechanical working of the metal.

2. The maximum attenuation rate for Iron-Chrome and Iron-Chrome-Manganese alloys have been observed at two ( $\alpha$ - **Fe** + $\sigma$ ) phase for **Fe-Cr** alloys and three ( $\alpha + \gamma + \sigma$ ) phase region for Fe-Cr-Mn alloys of the structural diagram .

3. The variety of alloying elements added to the iron or steel to modify its physical and mechanical properties as well as heat treatment, and mechanical working of the metal should be investigated for noise-reduction potential and nondestructive diagnostics of machinery and metals.

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**Table 1**

| *Sample I.D. Number* | *Chemical composition of the alloys* | | |
|---|---|---|---|
| | *C, %* | *Cr, %* | *Mn, %* |
| *0* | 0.029 | – | 0.43 |
| *1* | 0.043 | 0.32 | 0.71 |
| *2* | 0.024 | 0.80 | 0.87 |
| *3* | 0.033 | 0.85 | 1.02 |
| *4* | 0.019 | 1.57 | 1.26 |
| *5* | 0.019 | 1.96 | 1.42 |
| *6* | 0.033 | 3.17 | 1.59 |
| *7* | 0.033 | 4.25 | 1.65 |
| *8* | 0.039 | 5.38 | 1.68 |
| *9* | 0.014 | 9.88 | 2.20 |
| *10* | 0.038 | 14.96 | 2.90 |
| *11* | 0.033 | 18.99 | 4.80 |
| *12* | 0.043 | 21.66 | 9.92 |
| *13* | 0.033 | 25.25 | 12.35 |
| *14* | 0.023 | 29.69 | 28.30 |
| *15* | 0.013 | 34.67 | 39.68 |
| *16* | 0.019 | 43.55 | 52.01 |
| *17* | 0.012 | 59.92 | 58.56 |
| *70* | 0.095 | 14.90 | 10.48 |
| *71* | 0.095 | 17.81 | 10.65 |
| *72* | 0.067 | 22.70 | 12.51 |

* The samples after casting have been slowly cooled in the air

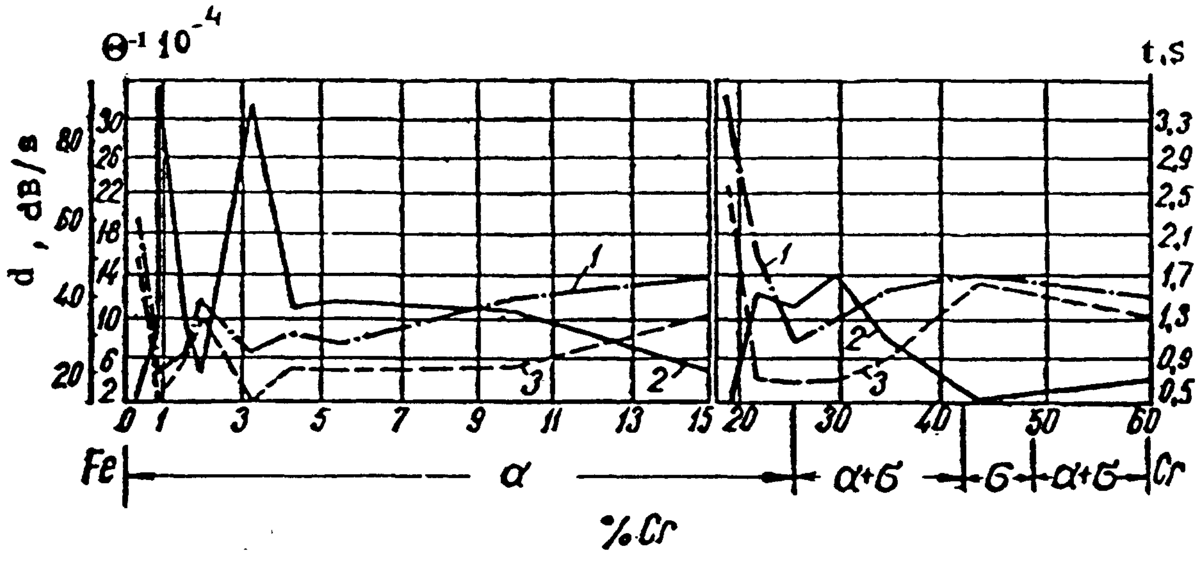

**Figure 1.** *CHANGE IN THE RATE OF THE SOUND ATTENUATION* **d** (1), *DURATION OF THE SOUND RADIATION* **t** ( 2 ), *AND INTERNAL FRICTION* $\Theta^{-1}$ (3 ) *OF THE IRON-CHROM ALLOYS*

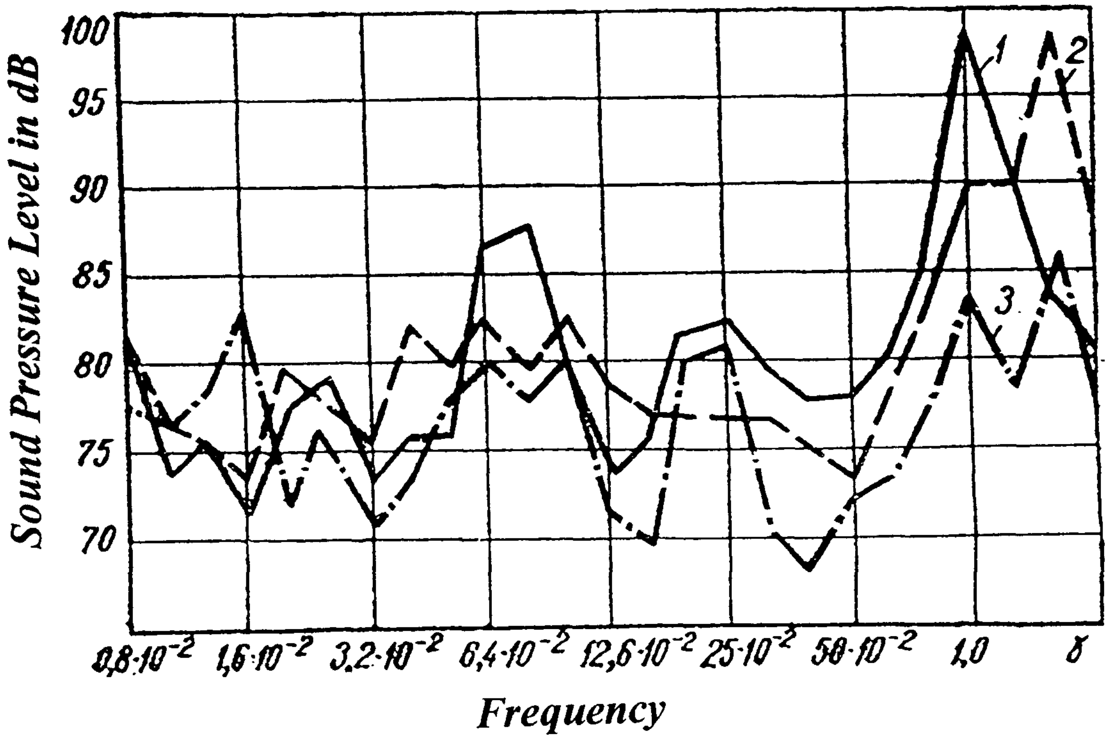

**Figure 2.** *RADIATED SOUND PRESSURE SPECTRUM FOR PLATES MADE FROM IRON-CHROM-MANGANESE* (**Fe - Cr - Mn** ) *ALLOYS*

1 - #70 ( 14.90%**Cr**, 10.48%**Mn** ); 2 - #71 ( 17.81%**Cr**, 10.65%**Mn**);

3 - #72 ( 22.70%**Cr**, 12.51%**Mn**)