Identification and reduction of vibration and noise of a glass tempering system

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Abstract. The vibration and noise of a glass tempering machine at a factory are studied. Experiments were conducted to identify the sources of vibration and noise. It was found that main sources for vibration and noise are two air barrels, the air pipes from the fans to the glass tempering machine and the fans location. Solutions were suggested to reduce vibration and noise from these three main sources. One of the solutions that were implemented is placing rubber dampers beneath the air barrels and pipes which almost cancelled the horizontal vibrations in the building structure and reduced the vertical vibrations to a low value most likely coming from noise. There are two types of noise, namely, radiation noise from the fans through the fans room walls and transmitted noise through the pipes caused by turbulence. A glass wool noise insulating layer was installed on the wall between the fans room and factory to reduce radiation noise through this wall. Part of the air pipe system in the factory is made of a light material which produced the highest levels of noise above 110 dBA. These air pipes were wrapped by glass wool rolls and the noise level near them was reduced to below 100 dBA which comes from other machine parts. In addition, noise levels were reduced between 2 and 15 dBA at different points in the factory.

1. Introduction
One of the major limitations at many industries is vibration and noise produced by machines. The problem of vibration and noise even extends to all kinds of buildings and automotive applications. Therefore, analysis of vibration and noise has been always an important issue for researchers. The solution or the reduction of these two factors is a mind bugling problem. The research presented in [1] proposes a novel tuned mass-damper-inerter passive vibration control configuration, to suppress the oscillatory motion of a support excited mechanical chain-like systems. The suggested technique improves performance. Identification of noises coming out from modern household refrigerators using Fourier analyses has been conducted in [2]. Solutions to reduce the noise level were suggested. Smart damping materials such as magnetorheological elastomers for noise and vibration in automotive applications were explored in [3]. In the research presented in [4], a new method is proposed in order to quickly estimate the noise emission in free space based on an approximated acoustic power of brake system. Recent research in the area of two-phase flow induced vibration in piping system can be found in [5].

The glass tempering system at a factory produced huge and undesired amount of noise and vibrations. This was really a dangerous situation because it could over the long run cause hearing damage to the factory staff and structural damage to the glass tempering system and the building containing the system. In addition, the performance of the glass tempering system could be...
deteriorated substantially and the glass could break or its properties would correspondingly differ from the desired and expected optimum ones. Therefore, it was extremely important to reduce the noise and vibrations to a minimum level through applying the appropriate and possible structural changes and noise control techniques.

The glass tempering system consists of three fans, pipe structure and rollers structure over which glass plates moves. The fans are located in a separate room and they pump air through the pipe structure to the glass. The pipe structure passes through two large barrels (air tanks) to regulate the air flow. Air reaches the glass through many small holes from both top and bottom.

Fans, pipe structure, air tanks, glass tempering system structure and air path were all possible noise and vibration sources. The huge amount of noise and vibrations could have a single source or a combination of sources. Therefore, the cause of the noise and vibration problem is being found and isolated appropriately. Possible noise and vibration sources were tested and analyzed. The solution to the problem requires knowledge and experience in engineering analysis and involves mechanical vibrations, control systems, noise control, instrumentation, fluid mechanics and dynamics.

The factory map including fans room, air tanks, air pipes, glass tempering machine and offices is shown in Figure 1. Note that the offices are located on the top floor and other parts are located on the bottom floor. Noise and vibration is generated in the bottom floor and propagates to the top floor.

![Factory Map Diagram]

**Figure 1.** Factory map.

2. **Identification of vibration and noise sources**

It is extremely important to reduce the noise and vibration at the factory to a minimum level through applying the appropriate and possible structural changes and noise control techniques. The causes of the noise and vibration problem were found and are being isolated appropriately. This goal was achieved by applying several different techniques. Using noise and vibration measuring instruments to locate the problem sources through appropriate tests was vital. However, the instruments locations and
how to operate the system during the tests were two important issues to solve. This depended on experience, understanding the system structure and engineering analysis which involves mechanical vibrations, control systems, noise control, instrumentation, fluid mechanics and dynamics. Another approach used was common sense which was supported by strong and logical reasoning. As testing and analysis of the noise and vibration sources proceeded new ideas and approaches were concluded towards solving the problem.

The following are the noise and vibration sources that were studied and analyzed:

1) Different pressure at different locations
   The air pressure out of the small holes and hitting the glass could vary with location. This would generate noise and vibrations due to the different forces at different locations of the glass tempering machine structure. This problem was tackled by measuring the air pressure at the different outlet air pipes. The pressure was equal at all outlets and therefore there is no discrepancy and this was not considered as a possible cause for noise and vibrations.

2) Different fans geometry including air path
   Each fan was operated alone while separating its pipe structure from the rest of the fans. The problem persisted for each fan operating separately. Therefore, all the fans were causing noise and vibrations.

3) Pipe structure imbalance
   The path through which air flows from the fan to the glass suffered from severe vibrations due to the air motion and inappropriate path shape and structure. It was found that the two barrels in the air path were a major cause of vibration. A measuring device (accelerometer) was used to determine the sources of mechanical vibrations in this case. Engineering analysis was used to suggest and implement appropriate solutions to reduce the vibrations to a minimum level.

4) Fan rotating imbalance
   Rotating imbalance occurs due to imperfect load distribution of the fan propeller and it causes huge amount of vertical vibrations. It was found that all the fans had dampers at their bases or mounts (contact points with ground) which absorbed the large amount of vibrations. This was verified by the experiments discussed later.

5) Fan horizontal vibrations
   Fan horizontal vibrations occur due to the conservation of momentum principle. When the fan pumps air out it is being pushed backwards. In addition, the pressure built up in the air pipes puts a force on the fans which could shake them severely. Two solutions were suggested to this vibration and noise cause. The first suggestion was to remove the connections between the factory building and fans that are affected by horizontal vibrations. This step was possible and it was implemented. The second suggestion was using vibration and noise reduction materials at the walls between the factory building and fans room which should reduce the noise levels. Note that the main source for noise is the fans since they contain the actuating parts, the motors.

3. Experimentation and measurements
   Data about the glass tempering system relevant to the noise and vibration problem were collected. The data included the weights and dimensions of the system components in addition to the rotational speeds of the fans. The collected data along with engineering principles helped in finding solutions to the noise and vibration problem.

   Experiments were conducted based on measuring devices, engineering analysis and logical reasoning to locate the vibration and noise sources precisely so that appropriate actions could be taken to reduce the levels of vibration and noise to the minimum possible situation. The measuring devices used were an accelerometer to measure the vibration level and a pressure gage to measure the air pressure. Other required data was available and did not need any measuring devices.

   In the first experiment the air pressure was measured out of the small holes and hitting the glass. There are 19440 holes which is a very large number. We selected several different locations covering the whole area of the system to measure the air pressure and decided if the pressure did not change at
the measured locations then it would not change at all locations. Indeed, the pressure was equal at all measured outlets and therefore there was no discrepancy and the pressure was not considered as a possible cause for vibration and noise.

In the second experiment the vibration level at many locations of the structure of the glass tempering system was measured using the accelerometer as shown in Figure 2. The locations included points on the ground and points at upper levels. The points on the ground are more important for determining mechanical vibrations transfer to the building. On the other hand the points on upper levels help in understanding how the vibrations propagate and in case the vibrations are large noise could be produced.

![Figure 2. Picture showing vibration measurement using the accelerometer.](image)

The vibration measurements were all very small (zero or very close to zero) except at the ground mounts (or bases) of the two large barrels through which air passes from the fans to the glass. The barrels task is to regulate the air flow to the glass through adjustable valves inside them. The ground mounts on which the barrels sit have rectangular shapes, made of steel and stand directly on the ground without any vibration attenuating components as can be seen in the picture of Figure 5. It was concluded that the barrels were the main source of mechanical vibrations in the building.

The accelerometer measures the mechanical vibration amplitude in m/s². Each fan has 12 mounting points which are isolated with dampers. There are three fans and therefore we have 36 mounts. The values recorded at the mounts are 0 at half of the mounts, 0.1 m/s² at 2 mounts, 0.2 m/s² at 2 mounts, 0.4 m/s² at 3 mounts, 0.5 m/s² at 3 mounts, 0.8 m/s² at 2 mounts, 0.9 m/s² at 2 mounts, 1.0 m/s² at 3 mounts, 1.1 m/s² at 1 mount, and 1.2 m/s² at 1 mount. In addition, the mechanical vibration level was measured at 7 different location at the barrels bases. All the readings were 17 m/s² on average which indicates clearly that the mechanical vibration problem is due to the barrel shaking.
4. Reduction of vibration and noise

In order to eliminate the vibrations from the barrels we needed to place appropriate dampers under the barrels ground mounts so that the vibrations are minimized and not transferred to the building. In order to obtain the appropriate dampers the weights of the two barrels and the sizes of the ground mounts were measured. A top view of the two barrels is shown in Figure 3. The first barrel weighs 1.1 tons and has two rectangular mounts each of width 8 cm and length 1.09 m. The second barrel weighs 1.2 tons and has two rectangular mounts each of width 48 cm and length 2.19 m.

![Figure 3](image_url)

**Figure 3.** Top view of the two barrels of the glass tempering system.

Dampers suppliers were contacted to check for available dampers and their properties. Suitable rubber dampers were found and bought. The dampers come in two sizes. The first size is 40x40x5 cm and can carry up to 5 tons. The second size is 10x53x5 cm and can carry up to 3 tons. These rubber dampers could be cut to have the appropriate sizes for the glass tempering system barrels. For barrel 1 two dampers of the size 10x53x5 cm were bought and cut into four pieces of size 10x26.5x5 cm which form four legs for the barrel. For barrel 2 three dampers of the size 40x40x5 cm were bought and cut into six pieces of size 40x20x5 cm which form six legs for the barrel. A picture of the two different sizes of dampers after cutting is shown in Figure 4.

The dampers were placed under the two barrels mounts as shown in the pictures of Figures 5 - 7. It was a challenging problem to lift the two barrels that were connected to other glass tempering system components. The best way to lift them was to use the available overhead crane and strong cables which were hooked to the barrels. First we placed the 10x26.5x5 cm rubber dampers beneath tank or barrel 1 and then we repeated the same procedure for tank 2 with the 40x20x5 cm dampers. After lifting each barrel, placing the dampers and releasing the barrel on the dampers the barrel did not go back to the leveled position and we had to level the barrel using the overhead crane with cables. Eventually, we had the two barrels leveled on the dampers.

The vibration level was measured on the barrel bases after placing the rubber dampers and was reduced from an amplitude of 17 m/s² to 7 m/s², which is a substantial reduction. Note that the mechanical vibration to the ground will be much less that 7 m/s² since the damper is located below the base at which we measured the mechanical vibrations. In case of the fans mounts the metal base where the mechanical vibrations were measured is below the damper and this is why we get smaller vibrations. After placing the dampers beneath the barrel bases the mechanical vibrations in the factory...
were not felt near the tempering machine but some shaking was still felt at offices of the factory which are located on the top floor. The factory is made of steel structure composed of hollow circular steel beams which are covered by concrete at many locations. One of these locations is the wall between the fans and the barrels. The air path from the fans to the barrels is made of steel and used to sit on the concrete without damping components. This was obviously a major vibration source that transfer vibrations through the steel structure and had to be isolated. The mechanical vibrations were measured on the uncovered steel circular bars in the factory and offices using the accelerometer to see how the vibrations propagate. All the vertical vibrations on the circular bars were measured as 0 m/s² which meant there were no vertical vibrations at all. We also measured the vertical vibrations on the offices floor and it was also 0. On the other hand, the circular steel bars were under horizontal vibrations. These vibrations were measured as 2.5 m/s² in the factory where the steel bars are away from the wall, and 12 and 16.5 m/s² at the offices whose wall is an extension of the wall between the fans and the glass tempering machines. Note that the steel structure is uncovered with concrete in the offices and this is why we could measure the horizontal and vertical vibrations there. It was concluded that the mechanical vibrations source was in the horizontal direction from the steel structure.

In order to eliminate the horizontal vibrations from the steel structure two 40x40x5 cm rubber dampers were bought. Each damper was split into two 20x40x5 cm parts that were placed beneath the air path at the connection point with the wall as shown in Figure 8. Other surrounding areas have a small gap between the air path and wall. After placing these dampers the horizontal mechanical vibrations were measured as 0 m/s² in the factory (was 2.5 m/s² previously) and 0 and 2.5 m/s².
(previously were 12 and 16.5 m/s², respectively). The situation became more comfortable in the offices and the mechanical vibrations were reduced a lot.

There is still something causing some shaking in the offices and the noise level was loud. The fans for the glass tempering machine produce huge amount of noise and are located in a closed room outside the factory building that shares one wall with the factory. This is the same wall through which the air pipe to the barrels pass and which extends to the offices. It is believed that since the sound level in the room is high, the room is closed and there are no noise insulators, the noise spreads through the factory and offices and could be also propagating through the hollow beams of the steel structure. The noise levels were measured by a sound level meter and were found as more than 110 dBA (or 130 dB based on linear combination of frequencies) in the factory and 73 dBA (or 85 dB based on linear combination of frequencies) in the offices, respectively, which are large. These amounts exceed the allowed limits of 85 dBA in industry and 55 dBA in offices. It became clear that the fans room should be noise isolated.

There are two types of noise, namely, radiation noise from the fans through the fans room walls and transmitted noise through the pipes caused by turbulence. A glass wool noise insulating layer of density 60 kg/m³ was installed on the wall between the fans room and factory containing the glass tempering machine to reduce radiation noise through this wall. After implementing this step the largest amount of noise was trapped in part of the air pipe system made of a light material which produced noise levels of above 110 dBA. These air pipes were wrapped by glass wool rolls of density 32 kg/m³ as shown in Figure 9 and the noise level near them was reduced to below 100 dBA which comes from other machine parts. In addition, noise levels were reduced between 2 and 15 dBA at different points in the factory. Transmitted and radiation noise are present partially from other locations which were identified. Reduction of noise levels from these locations requires covering the open areas of the glass tempering machine and thin air pipes with glass wool in addition to possibly glass wool insulation of the other fans room walls.

![Figure 5. Picture of the barrels without dampers.](image-url)
Figure 6. Picture of lifting the barrel.

Figure 7. Picture of the barrel base with the damper placed beneath it.
Figure 8. Picture of dampers beneath the air path at the connection point with the wall.

Figure 9. Picture of glass wool insulation of pipes made of light material.
5. Conclusion and future work
Placing the rubber dampers beneath the two air tanks (barrels) and air pipes was a very important step in alleviating the mechanical vibrations transfer to a factory building and reducing the noise level in a glass tempering system. In addition noise insulation of the wall shared between the fans room and factory, and the light air pipes from the barrels to the glass tempering machine was a crucial step to reduce the noise levels in the range 2 – 15 dBA at different locations in the factory. In regards to the vibration of the factory building, the main causing source was the transmission of vibrations through the two large air tanks and the air pipes sitting on the wall. These sources were eliminated. Nevertheless, it is worthwhile to look for other minor sources of mechanical vibrations and if they exist, they will be eliminated by applying the appropriate engineering solutions.

It was concluded from experiments done so far and logical reasoning that remaining noise sources are the open areas of the glass tempering machine and the thin parts of the air pipes. The open areas will be sealed with glass wool and the thin pipe parts will be insulated with glass wool rolls. This step should reduce the noise levels substantially. Other walls of the fans room will be insulated with glass wool if noise levels are still not acceptable.

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