

# Visualizing Vibration: Using Motion Amplification® for Troubleshooting Cement Industry Equipment

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**Abstract** - Motion Amplification® [1] is a video-based vibration analysis technology that enhances the visibility of subtle motion in machinery and structures, enabling engineers and technicians to rapidly diagnose mechanical issues. In the cement industry, where large-scale rotating equipment and complex systems are integral to production, this technology provides a non-contact, real-time diagnostic tool to identify misalignment, looseness, imbalance, and structural resonance. This paper presents real-world examples from cement manufacturing sites where Motion Amplification® was used to pinpoint root causes of failures, reduce downtime, and improve maintenance planning. The process involves capturing high-speed video of equipment in operation, amplifying sub-pixel movements, drawing regions of interest on video to extract, and diagnosing FFT spectra and time waveforms, and converting them into actionable insights. Results demonstrate the value of amplified motions as a cost-effective, efficient method for machinery troubleshooting, particularly in harsh and noisy industrial environments typical of cement facilities.

**Index Terms**--Vibration Control, Vibration Measurement, Accelerometers, Modal analysis, vibrations, vibrometers, resonance, motion measurement, image motion analysis, computer vision image processing

## I. INTRODUCTION

The technique of amplifying motions leverages a high-speed camera as a full-field vibration measurement, visualization, and communication device. The camera's pixels are converted to non-contact displacement sensors that measure subtle movements. All the vibration measurement points in the image are acquired simultaneously, enabling comparative analysis across the field of view in a rapid fashion. This solves multiple fundamental issues in today's standard contact-based vibrometer data collections, including the difficulty of outfitting large assets with physical sensors because it is costly and time-consuming due to the large number of sensors required to cover the entire asset, as well as all but eliminating spatial aliasing issues as discussed in [2]. This also ensures no interpolation or subsampling occurs. This process is nearly real-time and requires no surface preparation, which is a major advantage in the dusty, high-temperature environments of a cement manufacturing plant. The fact that all vibration measurement points are acquired simultaneously offers advantages over conventional vibration analysis, which uses a vibrometer and an accelerometer. In addition, technology allows the user to measure calibrated absolute displacement across the full field of view, providing a time waveform, orbit plots, and FFT spectrum for each measured location. An amplified motion video is supplemented with other full field vibration techniques, such as Motion and Phase Maps that produce colorized images of motion, that can show the intensity of motion both as an overall motion and for a specified vibration frequency. These images can be used together with Motion Amplification® videos to quickly analyze and understand the vibration frequencies in the scene. Videos can be filtered based on a specific frequency of interest, allowing the video to show only the motion at a given frequency or range of frequencies. This allows individual modes of vibration to be imaged directly. Other techniques, such as the placement of motion vectors, can also complement and enhance the understanding and analysis of the video. The technology also includes transient capabilities, allowing the user to Motion Amplify small motions on a moving target, which is perfect for diagnosing issues on equipment like rotary kilns. This includes tracking and measuring motion in a moving reference frame, including spectral analysis.

A key capability of this technology is the speed at which data and video processing is performed. Data processing is instant and can be done in real-time, making the technology field-ready. It is possible to quickly scan an area for a rapid evaluation for instant vibration troubleshooting and fault visualization. This allows the user to process the data on the spot and make changes in the field, which is key for root cause analysis and pinpointing the location of a motion or common machinery vibration fault. This technology can also be leveraged as a prescreening tool for placement of sensors by quickly assessing a scene and determining locations of movement that need to be monitored or measured with vibrometers, continuous monitoring systems using permanently mounted contact sensors, or wireless vibration measurement devices. This flexibility allows the user to rely on the tool as a rapid Operational Deflection Shape (ODS) and Modal Analysis without the overhead of time-consuming point collections and modeling. Motion Amplification® videos enhance the understanding of how components and their relationships create motion. This makes it a great early detection and troubleshooting tool, a quick and effective alternative to traditional ODS or Modal Analysis, and an effective communication tool between technical and non-technical resources.

Full-field vibration techniques and Motion Amplification® videos are useful as a non-contact method for dynamic and structural testing. They are particularly well-suited for the massive assets found in the cement industry, where common vibration faults such as imbalance, misalignment, structural looseness, and resonance can reduce the reliability of assets and cause business interruptions with unexpected failures. The ability to visualize and quantify the root causes of vibration faults allows for targeted and cost-effective maintenance planning, scheduling, and repairs. It minimizes production interruptions, costly downtime, and extends the lifespan of cement manufacturing equipment.

## II. TECHNIQUES

Technology works by making the motion in the video more visible. Every movement in the field of view has amplification applied to it uniformly, such that all motions become visible. Individual vibration frequencies can be filtered so the video only shows motion at a particular frequency. A typical Motion Amplification® video of a cement mill would show mechanical looseness that is imperceptible in normal video but is amplified to a level where the full dynamic motion is clear. This level of information enables engineers and technicians to make informed decisions about maintenance and repairs.

Fig 1. Shows a raw mill with significant base movement, primarily associated with the mill speed, which led to heightened displacement near the mill's top, reaching 57 mils across the coupling. Additionally, some pedestals exhibited noteworthy movement, partly linked to mill speed but primarily attributed to random vibration. Amplified motion, shaft inspection, and Motion & Phase Colorized Maps were used to identify vibration frequencies of interest, mainly related to mill and motor speeds (23 RPM and 896 RPM, respectively). With this data and recommended actions, the plant secured all hold-down bolts on all pedestals and scheduled Motion Amplification® follow-up recordings after the scheduled foundation repairs were performed for commissioning and baselining purposes.



Fig. 1. Raw mill with significant base movement.

In a camera-based vibration analysis system, the acquisition's sample rate is the camera's frame rate. All the same digital signal processing rules still apply, such as needing to sample at twice the rate of the maximum frequency you need to resolve. As such, high-speed cameras can be leveraged to increase the frame rate and thus the frequencies you can detect, making them suitable for high-speed machinery like dust collector fans.

The technology allows for displacement measurements to be made anywhere within the image to extract a time waveform, frequency spectrum, or orbit (X and Y) plots. This is done by drawing a box, or Region of Interest (ROI), in the image, and the displacement for that location is returned with calibrated, absolute units. The calibration is aided by inputting the distance to that location with a known value. This measurement is utilized to better understand the Motion Amplification® video and the amount of displacement that is occurring. Orbits (X and Y plots) are extremely valuable for analyzing motion on a trunnion bearing to visualize if it may be pulling away from the drum. The FFT spectra are also utilized as an aid to determine frequency-based filtering, which is essential for isolating specific issues on a mill. Filtering techniques can also be applied to help analyze between pinion or bull gear issues.

Reacting to and repairing symptoms of equipment vibration can temporarily improve the condition, but getting to the root cause should always be a priority. Motion Amplification® was done before and after structural cracks were repaired, and vibration decreased on a vertical mill. However, the root cause had not yet been addressed. Motion Amplification® was used to detect structural cracks and vibration issues in the mill, as shown in Fig. 2.

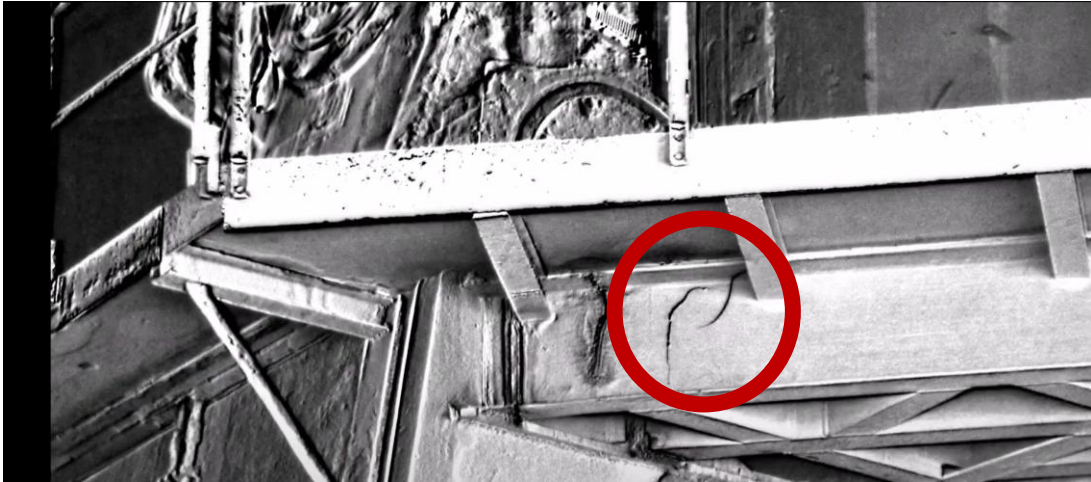


Fig. 2. Vertical mill with structural cracks. Amplified motion

**Motion Map** is a technique that allows for the colorized mapping of the motion across an entire image. This can be the overall motion or frequency-specific motion. The result is a colorized image of motion, with the motion mapping technique providing a rapid way to analyze the motion in a field to quickly understand the dynamics and motions present, along with relationships of motion. A Motion Map of a cement or material handling system mill can quickly show the areas of highest vibration, whether it's the machine, the foundation, or the surrounding structures.



Fig. 3. A regular image of the scene for which the Motion Map in Fig. 4 was applied.

Fig. 4 shows a Motion Map in an industrial setting. The red areas indicate an area of increased motion. In this case, the map shows 8.82 Hz, which is the running speed of the pump that the Motion Map is accentuating. Also visible are increased levels of vibration in the pipework. In this image, you can see how the pump drives the piping vibration, causing vibration outside the area of the pump itself. A complex vibration scene is easily represented in a single image. Fig. 4 is the Motion Map showing the motions present in the field of view. In this example, the motion has been filtered to 8.82 Hz, the frequency at which the pump is operating. Fig. 3 shows the regular image.



Fig. 4. Motion Map

**Phase Map** is a technique by which a colorized, full-field phase overlay can be applied to an image, showing the relative phase for a given frequency across the entire image. Like a Motion Map, this gives a quick and comprehensive view of the entire field of vibration, indicating which areas of the image are in and out of phase with one another at a particular frequency. This is particularly helpful for diagnosing issues with shafts and bearings, such as a  $180^\circ$  relative phase shift across a coupling, which indicates misalignment. Phase uses color to convey the phase relationship of different asset components. Fig. 5 shows a cement raw mill; the relative phase is shown filtered at 23 RPM.

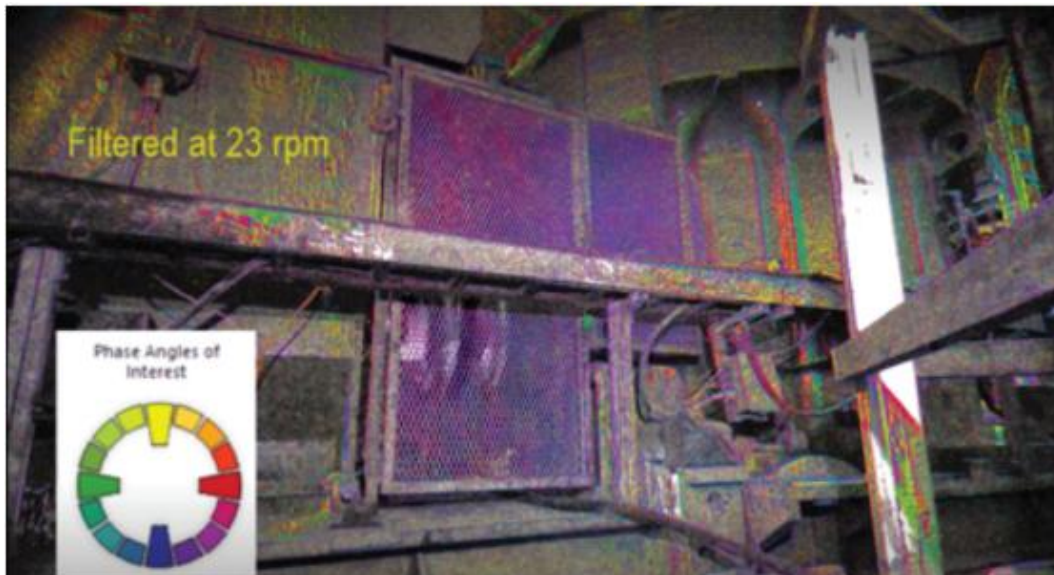


Fig. 5. Phase Map.

**Frequency-based filtering** is a technique that refers to filtering the video data to show motion only at a particular frequency. Individual frequencies are important to image to gain a better understanding of the item under investigation, whether you are troubleshooting a piece of machinery, imaging a resonance, or understanding mode shapes of an object, as

discussed in [3]. For example, by filtering a video of a machine structure to its natural frequency, you can see a resonant mode that is causing excessive vibration and fatigue on the structure.

**Vector overlays** are a useful way to visualize complex motion across a full field of view. Any location that has been measured can be transformed into a vector since the X and Y components have been determined. This makes it particularly useful for complex fields of motion where the vectors visually correlate the motion to show particular patterns. This is illustrated in Fig. 6, vectors highlighting the 4<sup>th</sup> bending mode of a cantilever beam through a filtered, Motion Amplification® video. During playback, these vectors are animated, showing the dynamic motion of the object as it moves. These modes are further discussed in [4].

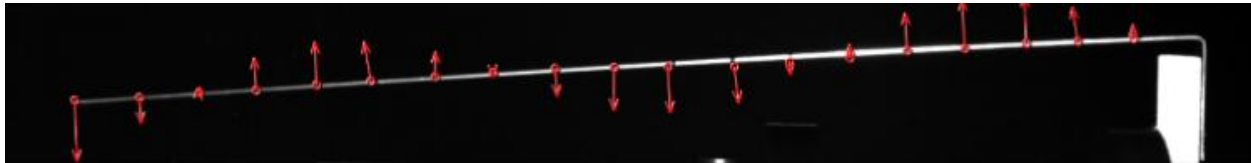


Fig. 6. Vector Overlays

Rotating components are challenging to measure because their vibrations and motions of interest often appear only when they are in motion. The techniques presented here show how a camera can leverage the full field for these measurements. The camera can be put in a special mode that accounts for the turning speed of the rotating components, allowing the scene to be imaged at a rate that makes the rotating component visible and unblurred. This allows for a visual inspection of couplings and shafts during operation. A second technique is synchronous triggered acquisition, where the camera's frame rate is synchronized with an external signal such as a tachometer. The result is an acquisition captured at synchronous speeds, effectively freezing the rotating element. Motion Amplification® can then be applied, along with time waveform and spectral measurements, to image and visualize non-synchronous motion. This technique can be extremely useful for troubleshooting and quantifying displacements on rotating objects.

**Tach Sync** on a coupling using a high-speed camera with an external tachometer, and amplifying motion allows engineers and technicians to capture the full motion of a mill's coupling, visualizing misalignment or looseness. By analyzing the time waveform, orbit plots, and spectrum, it's possible to determine if the motion is due to misalignment, structural resonance, or other forcing functions. Illustrated in Fig. 7.

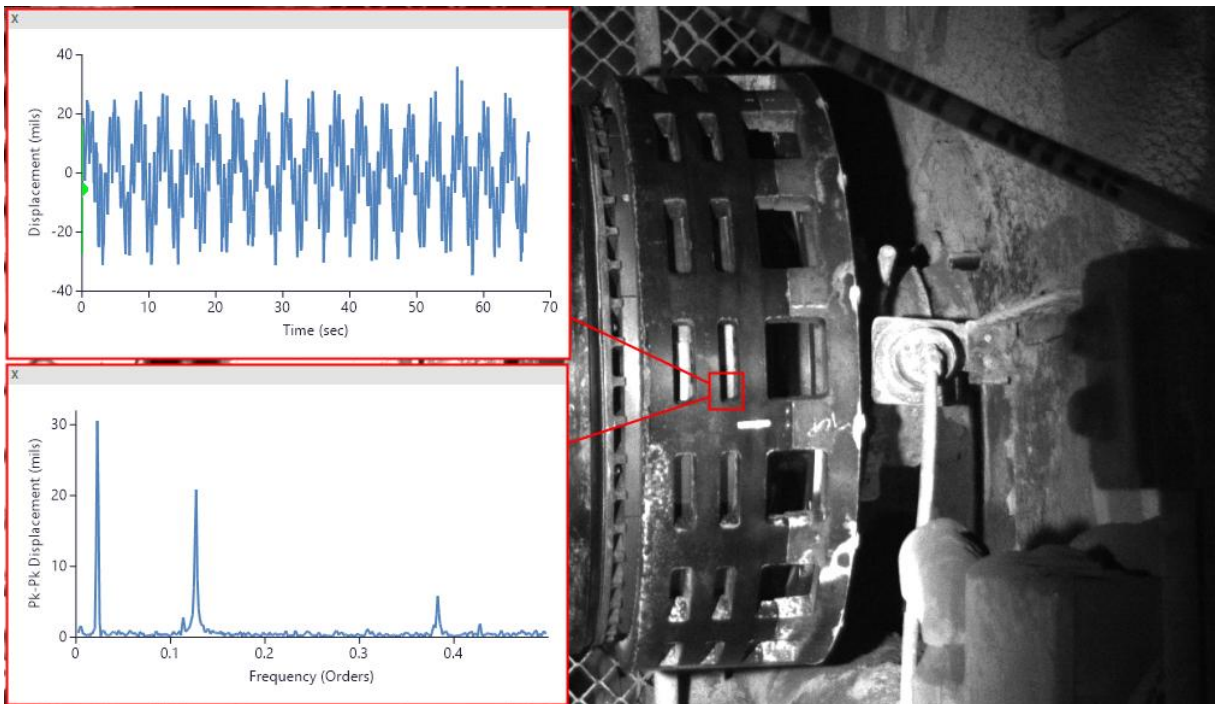


Fig. 7. Mill coupling displacement graph.

Much of the discussion has centered around higher-frequency and/or periodic motion. Motion Amplification® videos and subsequent measurements can also be applied to thermal growth measurements taken on a longer timescale, such as hours. By leveraging a high-speed camera to take data over a much longer and usually less sparsely sampled time period, long-term recordings can be acquired. Here, the goal is to capture motion that is generally not periodic but may happen only once per recording. Thermal growth measurements can be made and, perhaps more interestingly, can be seen in Motion Amplification® videos, allowing for a better understanding of the thermal growth itself, as well as which elements of an asset are affected and by how much. Fig. 8 is an example of using Motion Amplification® and displacement data to visualize and quantify the thermal growth of a preheater tower.

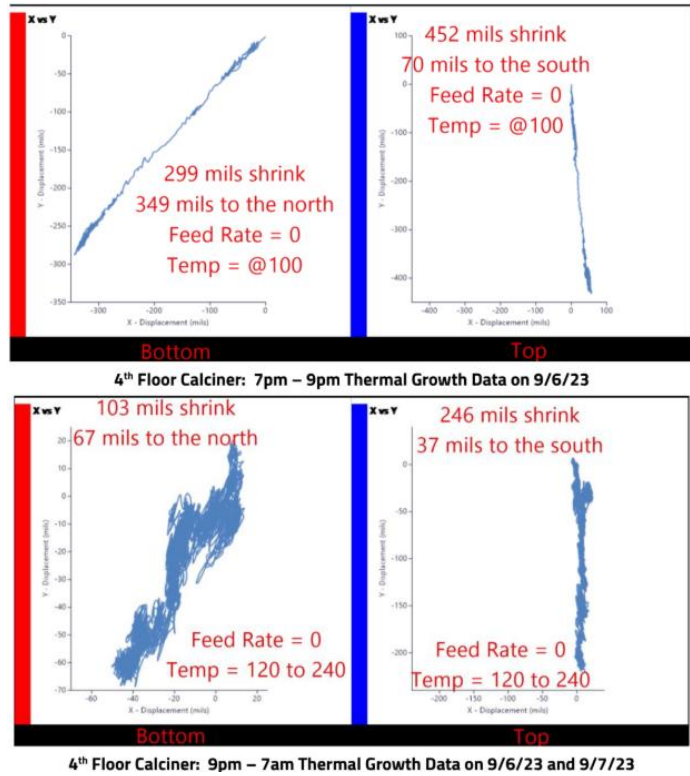
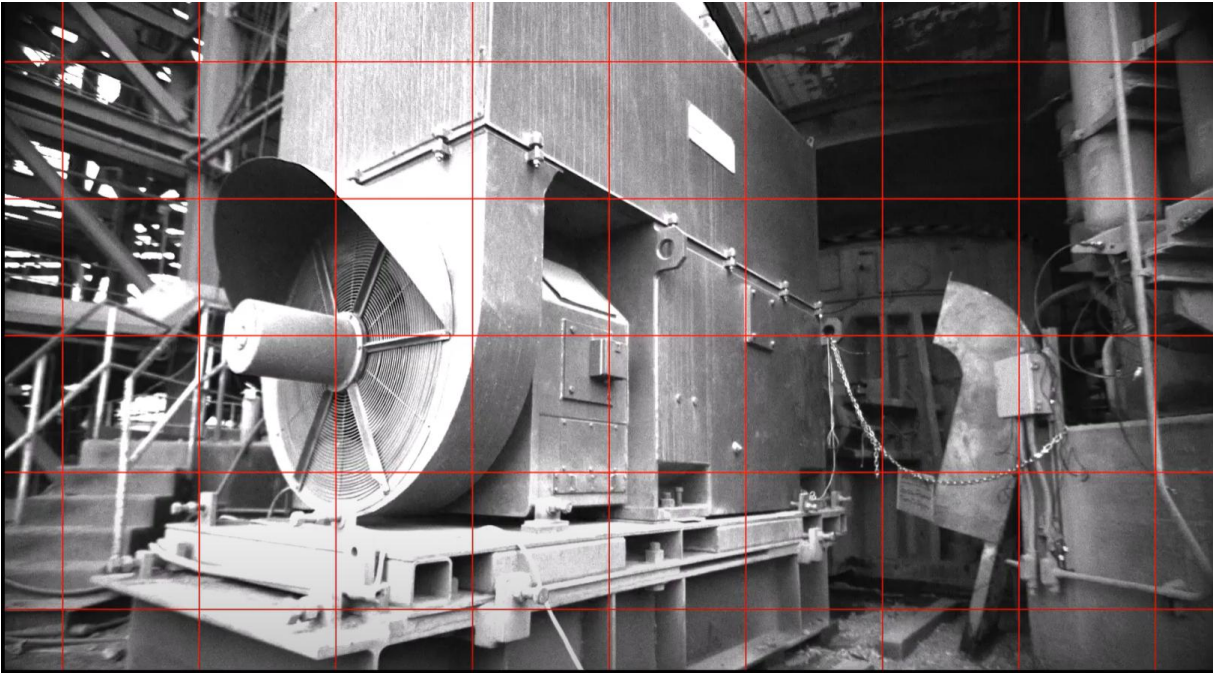
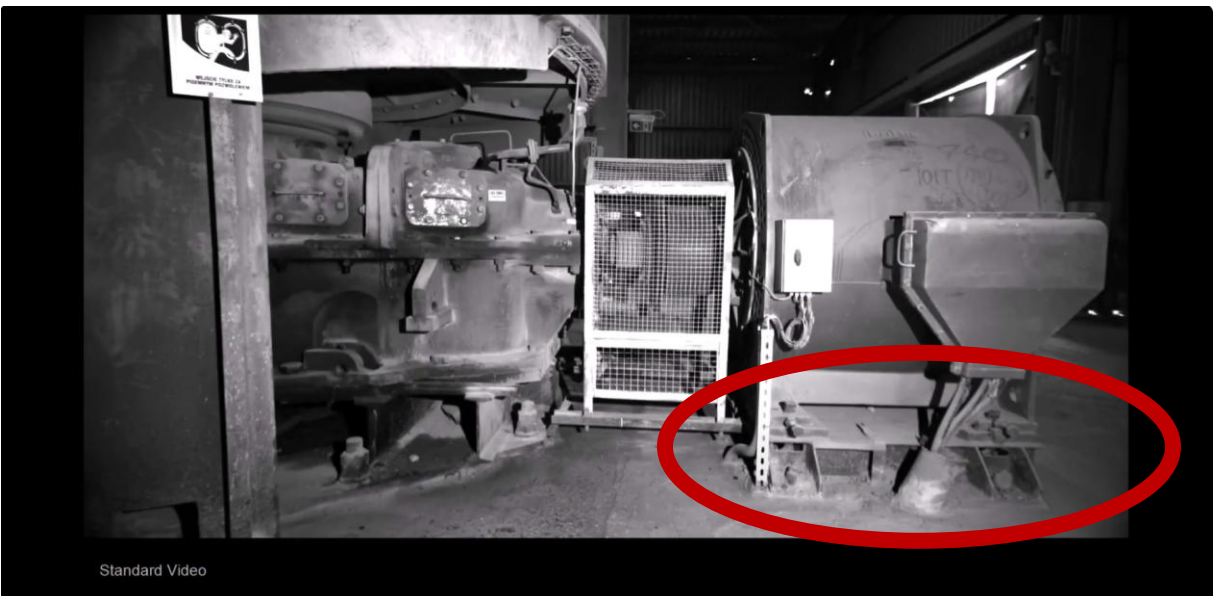


Fig. 8. Thermal growth visualization and amplified motion.

### III. ADDITIONAL EXAMPLES



Cement Raw Mill Motor and Base: Resonance and mechanical looseness were identified and visualized using amplified motion.



Cement Mill Motor: Issue with motor soft foot was identified using amplified motion.

#### IV. CONCLUSIONS

Amplifying motion and the accompanying full-field vibration techniques presented here demonstrate the usefulness of using this technology to assist with measurements on complex or large assets found in the cement industry. This is especially helpful where traditional sensors are cumbersome, time-consuming, or difficult to use. In the cement industry, where equipment is massive, operates in dusty and harsh environments, and is critical to production, this technology offers a more efficient and effective way to diagnose problems. It can be used to monitor the dynamic behavior of motors, dust collectors, fans, mills, rotary kilns, and conveyors, and to identify the root cause of vibration issues and thermal growth.

Full-field vibration analysis and Motion Amplification® videos offer an unparalleled view of a target due to the enormous amount of data they provide in such a short amount of time. This provides more information on the specific asset being imaged, as well as the surrounding and often impacting elements.

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Note: |

To view Motion Amplification® videos of examples shown in figures 1, 2, 6, 7 and additional examples, please visit [RDI Tech](#)

#### REFERENCES

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