26. Symposium Bauwerksdynamik und Erschütterungsmessungen, 27. Juni 2025, Empa Dübendorf

BaudynSymp2025_09_Kramar-ZieglerConsultants-etal.pdf

Monitoring System for Press-Induced Building Vibrations

Miha Kramar, Daniel Gsell, Cosmas Savary, ZC Ziegler Consultants AG, Zürich, CH

Abstract

This report presents the design and implementation of a permanent monitoring system installed at V-ZUG AG's production facility in Zug, Switzerland. The system was developed to track building vibrations generated by two newly installed servo-transfer press machines. The production hall housing these machines is located near both office and residential buildings.

Preliminary simulations and field measurements indicated that low-frequency loads of the presses — combined with high-frequency tooling impacts—could generate perceptible vibrations and structure-borne noise in both existing and planned neighbouring buildings. In response, the site owner commissioned an automated monitoring system to maintain oversight of production-related impacts.

The system employs MEMS-based accelerometers mounted on the press beds, on the foundations, and on nearby floor slabs in adjacent buildings. Data from these sensors feed into a custom MATLAB routine that performs both real-time and periodic evaluations. Each one-minute data file is automatically processed upon upload: stroke rates are extracted, vibration responses are compared with ISO 10137 comfort criteria, and diagnostic results are displayed on a browser-based dashboard. A secondary analysis cycle delivers six-hour summary reports for archiving and documentation.

The methodology combines harmonic decomposition, signal filtering, and conservative amplification models to assess vertical and horizontal vibration components. Additionally, a high-frequency spectral analysis quantifies structure-borne noise. Limit values for foundation forces and occupant comfort ensure that all press operations remain within acceptable bounds.

The system is fully scalable—additional sensors can be incorporated with minimal configuration—and adaptable; processing parameters can be tuned to monitor other machines as production requirements evolve.

Monitoring System for Press-Induced Building Vibrations

Miha Kramar, Daniel Gsell, Cosmas Savary, ZC Ziegler Consultants AG, Zürich

Abstract

This report presents the design and implementation of a permanent monitoring system installed at V-ZUG AG's production facility in Zug, Switzerland. The system was developed to track building vibrations generated by two newly installed servo-transfer press machines. The production hall housing these machines is located near both office and residential buildings.

Preliminary simulations and field measurements indicated that low-frequency loads of the presses — combined with high-frequency tooling impacts—could generate perceptible vibrations and structure-borne noise in both existing and planned neighbouring buildings. In response, the site owner commissioned an automated monitoring system to maintain oversight of production-related impacts.

The system employs MEMS-based accelerometers mounted on the press beds, on the foundations, and on nearby floor slabs in adjacent buildings. Data from these sensors feed into a custom MATLAB routine that performs both real-time and periodic evaluations. Each one-minute data file is automatically processed upon upload: stroke rates are extracted, vibration responses are compared with ISO 10137 comfort criteria, and diagnostic results are displayed on a browser-based dashboard. A secondary analysis cycle delivers six-hour summary reports for archiving and documentation.

The methodology combines harmonic decomposition, signal filtering, and conservative amplification models to assess vertical and horizontal vibration components. Additionally, a high-frequency spectral analysis quantifies structure-borne noise. Limit values for foundation forces and occupant comfort ensure that all press operations remain within acceptable bounds.

The system is fully scalable—additional sensors can be incorporated with minimal configuration—and adaptable; processing parameters can be tuned to monitor other machines as production requirements evolve.

1 Introduction

V-ZUG AG, a leading Swiss manufacturer of household appliances, has recently installed two large servo-transfer press machines in its production hall in Zug (Switzerland) which is located in the area with both office and residential buildings. The machines move more than a hundred tonnes of mass vertically in cycles along a ram motion curve defined by the forming and cutting process (Figure 1.1). Operational stroke rates vary from approximately 12 to 40 strokes per minute (spm), producing dominant excitation frequencies between 0.2 Hz and 0.67 Hz.

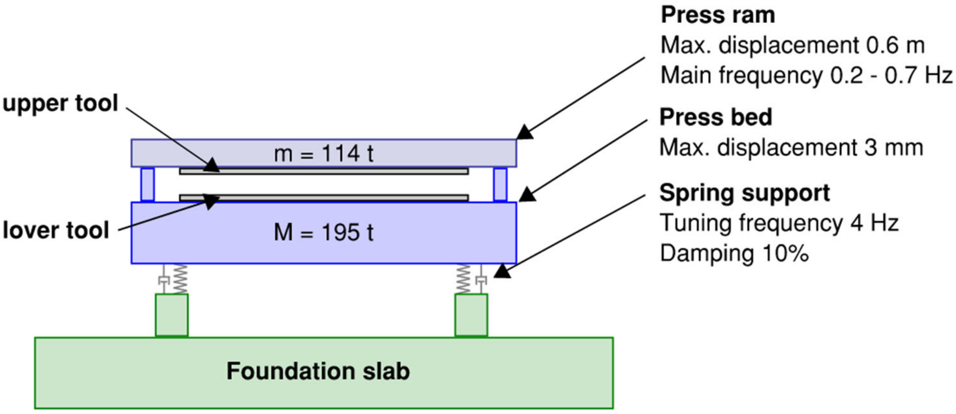

Figure 1.1 Schematic presentation of a press machine

During the design phase of the production hall, numerical simulations and preliminary field tests indicated that the low-frequency forces produced by the press machines could excite nearby structures, leading to perceptible vibrations and potential serviceability issues. Additionally, high-frequency tooling impacts contribute to structure-borne noise. To mitigate these effects on adjacent buildings, production was initially restricted: only eight ram-motion profiles are currently approved, limiting operational flexibility. Any new motion profile must demonstrate that it does not compromise occupant comfort in surrounding buildings before it can be authorized.

To monitor production and ensure objective data is available in case of complaints from nearby residents, the site owner commissioned a permanent vibration monitoring system. The system also supports future production flexibility, with its data serving as the basis for evaluating and approving new ram-motion profiles.

This report outlines the conception, implementation, and initial performance of the monitoring system.

2 Instrumentation

The monitoring system currently consists of eight measurement points that capture both the movement of the press beds and the structural response in nearby buildings (Figure 2.1).

Sensors differ by connectivity—some are hard-wired, others use 4G modules—and by mounting location, being fixed either to the press bed (MP 0, MP 1, MP 2), the foundation slab (MP 3, MP 4, MP 9), or selected floor slabs (MP 5, MP 6). Measuring points on the floor slabs are checking the vibrations in the existing buildings, while the measuring points on the foundation slabs were installed to make predictions for buildings not yet constructed.

To record low-frequency motion (< 1 Hz) as well as higher harmonics, each point employs a SYSCOM MR3003C recorder fitted with an MS 2010+ MEMS accelerometer. The devices have a large dynamic range (from 0.14 to 1.4×10^5 mm/s²) and a linear frequency response from DC to 460 Hz, enabling the detection of both very weak and very strong accelerations. All units are time-synchronized via Network Time Protocol (NTP).

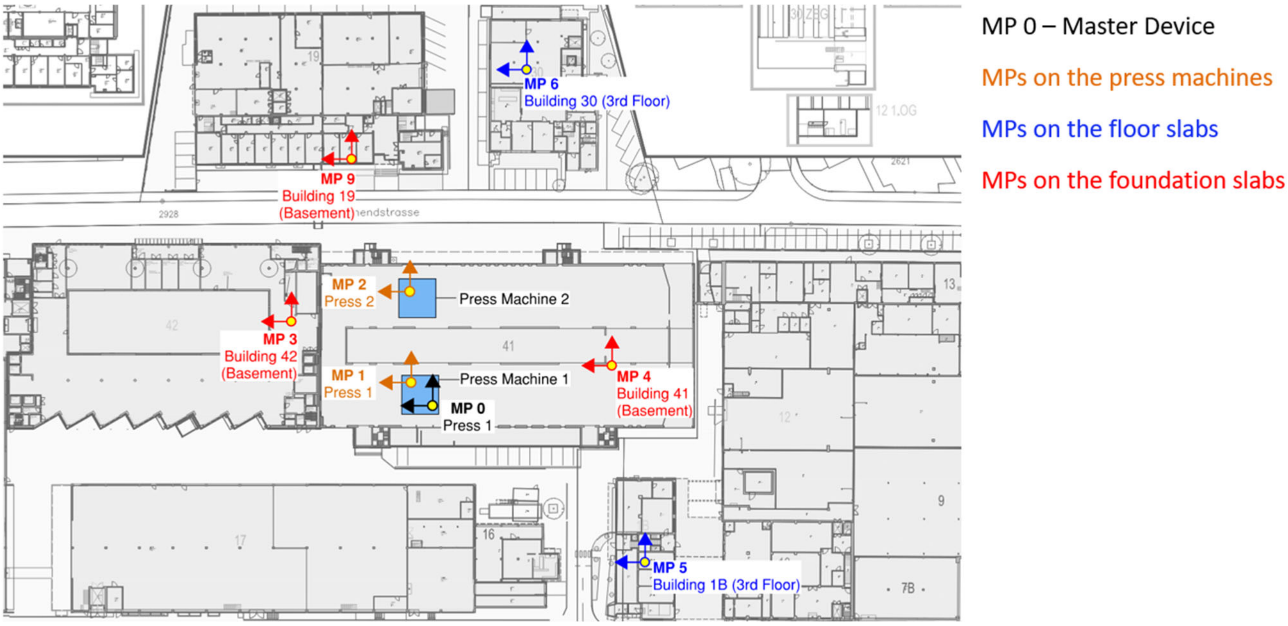

Figure 2.1 Location of Measurement points

3 Data-Acquisition Workflow

Figure 3.1 depicts the control and recording workflow of the monitoring system. The two press machines are wired to an OR relay, so a trigger pulse from either machine issues the Start-Recording command to the master device. This master device immediately triggers the recording on all other Stationary measuring devices, referred to as slave devices. The devices record 60-second files and upload them instantly to the internal V-ZUG file server via SFTP (SSH File Transfer Protocol).

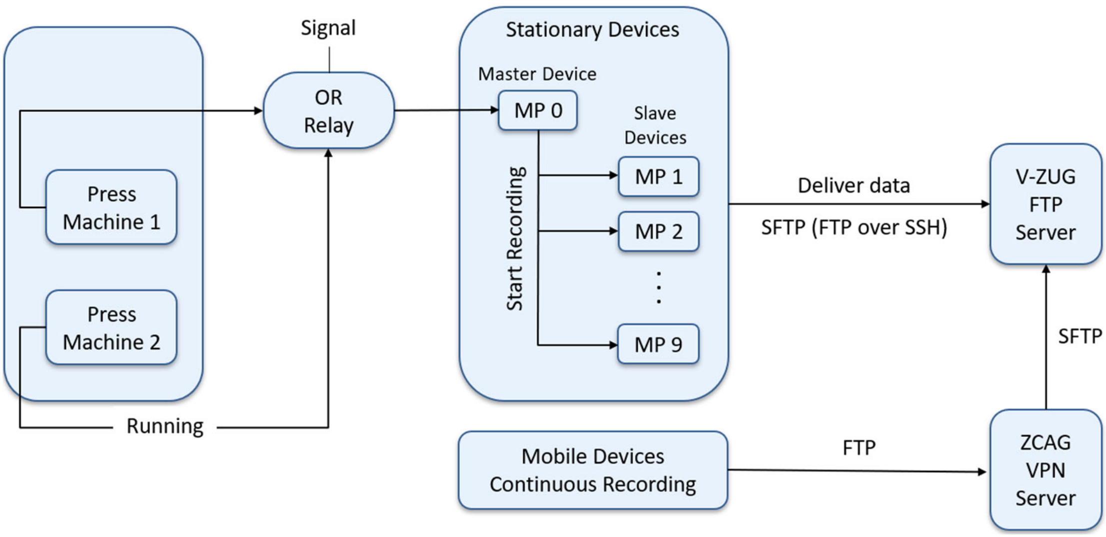

Figure 3.1 Data-Acquisition Workflow

In parallel, mobile monitoring devices record continuously, splitting the stream into 60-second files regardless of press activity. These units communicate through a 4G modem, first sending their files to the ZCAG VPN server, which then forwards them to the V-ZUG server over the same SFTP channel.

4 Monitoring Routine

In the subsequent processing stage, an automated monitoring routine written in MATLAB R2024b operates on the V-ZUG server. The algorithm continuously polls the master FTP directory for newly uploaded data. When a fresh file appears, it downloads the recordings from every measurement point, skipping any measurement point whose file is missing or corrupt. The program first attempts to compute the press-stroke rate using the signals from measurement points MP 1 (Press machine 1) and MP 2 (Press machine 2); if this calculation fails, the loop simply restarts and waits for the next upload. Once a valid stroke rate has been obtained, the software analyzes the data from the remaining measurement points, produces diagnostic plots and status reports, transfers these results back to the FTP server, and then returns to the start of the loop to await the next data set.

5 Data Evaluation

Data evaluation within the monitoring routine proceeds in two main stages. It begins with identifying the stroke rate of each press machine. Using these stroke rates, the routine then quantifies the foundation forces beneath the press machines, the resulting vibrations in the existing buildings, and predicts the vibration levels expected in the planned buildings (see Figure 5.1). Independently, an analysis of high-frequency vibrations is conducted at selected measurement points to characterize structure-borne noise. The following sections describe each component of the evaluation in detail.

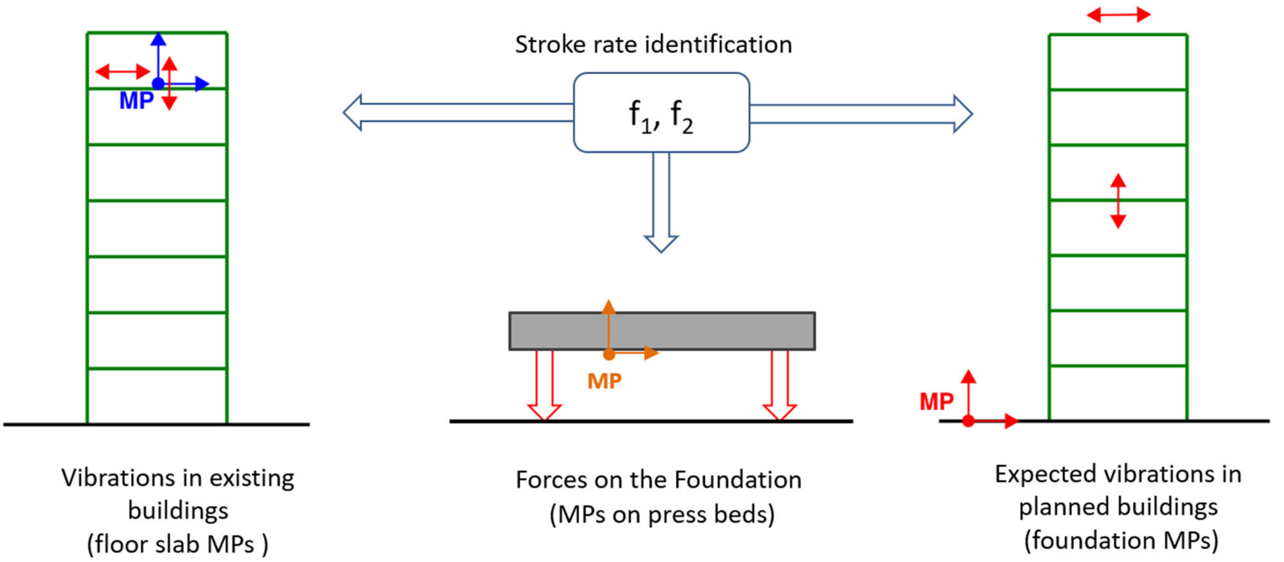

Figure 5.1 Data evaluation components

<u>Stroke-rate identification</u>

Stroke-rate detection is applied only to measurement points MP 1 and MP 2, whose Z-channels record the vertical acceleration of the press bed (Figure 1.1). The signal is first rectified and its amplitude envelope extracted by low-pass smoothing with a 0.1 s moving-average window, implemented with zero-phase filtering to avoid any time shift. The algorithm then computes the normalized autocorrelation of this envelope. In the resulting autocorrelation curve, the first significant peak that follows the zero-lag peak marks the fundamental repetition period of the press strokes; the stroke rate is the reciprocal of this period.

<u>Determination of forces on the foundation</u>

After the stroke frequency has been identified, the vertical-acceleration signals from measuring points MP 1 and MP 2 are expanded into a harmonic series whose components lie at integer multiples of the fundamental frequency. The number of harmonics is set to the larger of 30 or the value that brings the upper limit of the series to at least 15 Hz, ensuring the relevant frequency range is covered. For each harmonic, the combined sine- and cosine-terms give its vibration amplitude. These acceleration amplitudes are converted to displacement amplitudes by dividing by the square of the fundamental angular frequency. Finally, each displacement amplitude is multiplied by the press-support stiffness K_1 to obtain the corresponding force amplitudes.

Estimation of vibrations (horizontal and vertical) in existing buildings

For the measurement points located at mid-span of the existing floor slabs, the evaluation procedure is as follows. Both the horizontal and vertical acceleration records are decomposed with a multi-harmonic Fourier series that uses the two fundamental stroke frequencies identified at MP 1 and MP 2. This spectral reconstruction acts as a filter, retaining only those harmonics generated by the presses and suppressing unrelated vibration. In the vertical axis, the envelope's peak acceleration from the filtered time trace is extracted and compared directly with the ISO threshold (see chapter 6). In the horizontal axes, the algorithm first identifies the dominant frequency in each direction, corresponding to the building's eigenfrequency. These dominant frequencies are then used as reference points on the ISO 10137 acceleration limit curves. Taking a conservative approach, the maximum filtered horizontal acceleration is checked against those limit curves.

Prediction of vibrations (horizontal and vertical) in planned buildings

The analysis addresses two vibration modes: vertical floor-slab motion and horizontal sway at the building's top storey, both derived from foundation measurements. In the vertical case, the foundation-acceleration records are decomposed into a multi-harmonic Fourier series with two base frequencies; each harmonic is scaled by an amplification factor taken from a resonance curve defined by an 8 Hz slab natural frequency and 4 % damping, and the signal is then re-synthesized. The peak vertical acceleration of this filtered trace is compared with the ISO 10137 comfort threshold (see chapter 6).

Horizontal response is estimated by treating vertical wave motion as a small, harmonic ground tilt that excites building rocking. Assuming, conservatively, that the building's horizontal natural frequency always matches an integer multiple of the press stroke frequency, the resulting amplification is applied to the Fourier components of the foundation data. The derived horizontal accelerations, calculated in the frequency domain, are finally checked against the ISO 10137 limit curves (chapter 6).

High-frequency analysis for structure-borne noise

Structure-borne noise is assessed using the raw vertical vibration records. Each 60-second trace is windowed with a Hann taper and transformed using a Fast Fourier Transform (FFT). From the resulting spectrum, the root mean square (RMS) amplitude is calculated over the frequency range up to 280 Hz. This RMS value is taken as the reference magnitude of the structure-borne sound. No strict limit can be set, because the sound ultimately radiated into a room depends strongly on the building's structural details, non-load-bearing elements, furnishing, etc.

6 Limit Values

The vibration evaluation is governed by two main criteria: foundation-force thresholds that restrict the dynamic load transmitted by the presses, and human-comfort thresholds that limit the vertical and horizontal accelerations experienced in the nearby buildings (based on standard ISO 10137).

Foundation forces

The foundation force limits were derived in a previous study by correlating dynamic forces at the press foundations with predicted horizontal accelerations in neighbouring buildings, assuming arbitrary eigenfrequencies for the buildings. The limit curve was defined to ensure that these accelerations consistently remained below the comfort threshold. The resulting limit takes the form of a stepped envelope that constrains the allowable resultant force within the 0.75 Hz to 6 Hz range (see Figure 6.1), with permissible values decreasing as frequency increases. Each harmonic force component calculated for the press foundation must lie below this envelope. (Note: The range 0.75 Hz to 6 Hz represents the realistic range of building eigenfrequencies; outside this range, the curve is not governing)

Vertical accelerations

ISO 10137 provides a frequency-dependent comfort threshold curve. For simplicity and conservatism, a constant minimum value of 0.005 m/s² (RMS) across the full frequency range is adopted. Converting this to a peak value (by multiplying by 1.414) and applying the residential use factor R=1.4 from ISO Table C.1 yields a uniform limit of approximately 0.01 m/s² (peak) for all floor locations.

Horizontal accelerations

For horizontal motion, ISO 10137 likewise defines a frequency-dependent threshold curve. The curve is referenced in RMS terms; it is likewise multiplied by 1.414 for peak comparison and scaled by the residential factor 1.4. The resulting limit therefore lies at roughly 0.007 m/s² (minimum) between 1 and 2 Hz and rising to approximately 0.036 m/s² at 10 Hz (Figure 6.1).

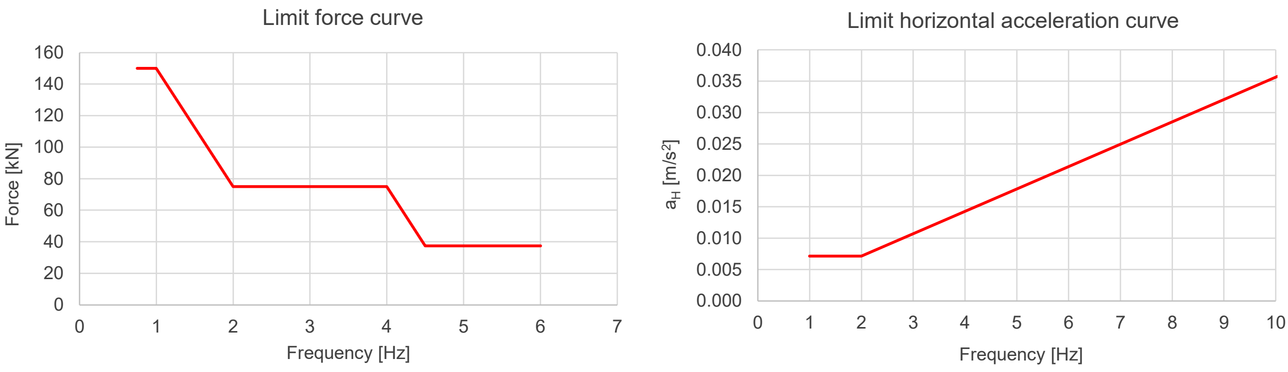

Figure 6.1 Force and acceleration limit curves in frequency domain

All predicted or measured vertical responses are evaluated in the time domain against the single-value peak limit defined above. Horizontal responses, on the other hand, are assessed in the frequency domain by plotting the acceleration components (Fourier coefficients) and comparing each ordinate against the scaled ISO curve.

7 Data Visualization and Reporting

The monitoring routine delivers two complementary views: a real-time dashboard that updates every minute while the presses are running, and a retrospective “time-lag” report generated at regular intervals (currently every six hours). Both displays distinguish between three sensor categories—press-table, foundation and floor-slab MPs—and compare their key response quantities with the applicable limit curves.

Real-time dashboard

For each Measuring point the programme plots its governing response in a single composite chart: press-table MPs show the harmonic foundation forces up to 8 Hz together with the calculated stroke rate; foundation MPs display the predicted peak vertical time-history and the predicted horizontal acceleration components; floor-slab MPs present the measured “filtered” vertical time-history and the dominant horizontal components. A colour-coded “traffic-light” panel summarizes compliance at a glance: green when all components are below 80 % of the limit, orange between 80 % and 100 %, and red whenever a limit is exceeded. The dashboard—timestamped and auto-refreshed—can be viewed on any browser or via remote desktop.

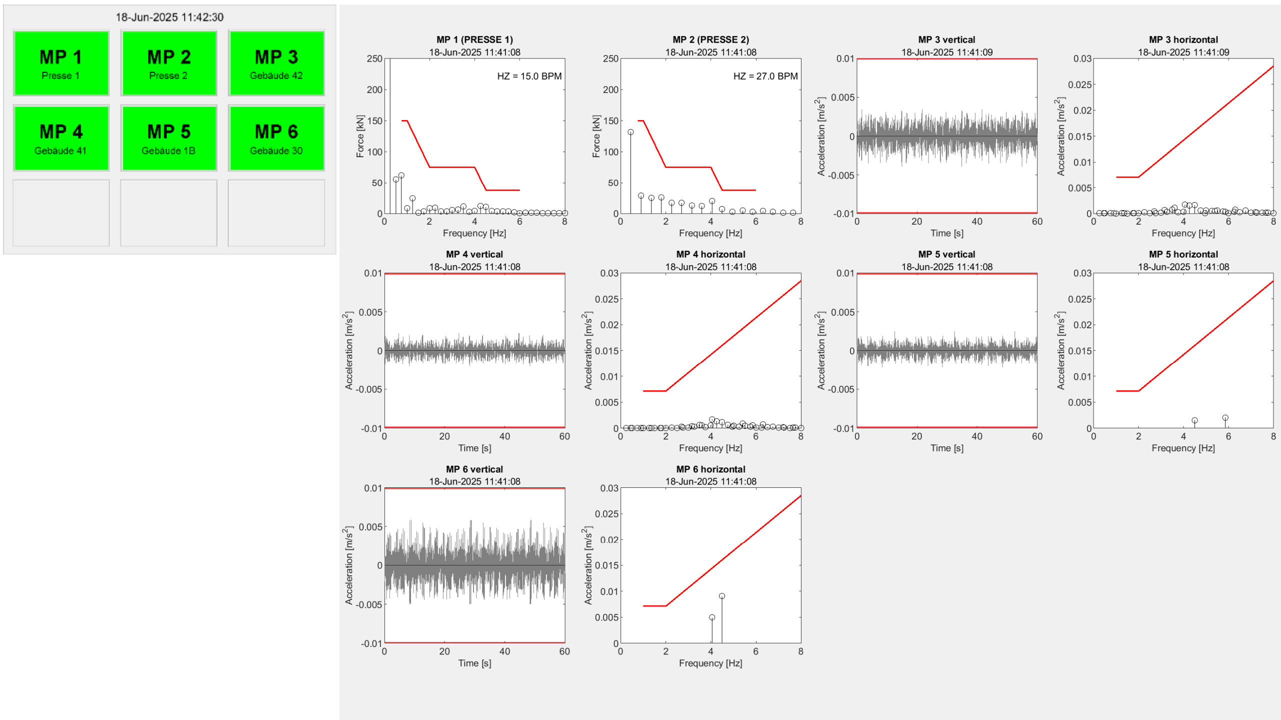

Figure 7.1 Example of Real-time dashboard

<u>Time-lag analysis</u>

At each scheduled interval the monitoring routine reviews the one-minute files on the server, repeats the calculations described above, and charts every parameter over time as a percentage of its respective limit (stroke rate and structure-borne noise are plotted in absolute units). Breaks in the time-history curves mark periods when the presses were idle. The resulting graphics are assembled into a PDF whose filename contains the end-time of the evaluation window; this report, together with the corresponding raw and processed data, is then archived on the FTP server.

8 Conclusions

A monitoring set-up has been developed to track the low-frequency vibrations generated by two servo-transfer presses and their effect on nearby buildings. The system combines MEMS accelerometers with automated signal processing and a uniform visual dashboard, all hosted on the company's internal network.

Eight sensors are currently installed on the presses, the foundations of nearby buildings and selected floor slabs. New sensors can be added by entering their type and orientation in software; the same analysis routines and plots then apply without further changes.

Data are evaluated in two stages:

- Real-time check – each one-minute file is processed as soon as it reaches the server; key responses are compared with the relevant limit curves and shown on the live dashboard.
- Periodic review – at set intervals the same files are re-analysed, the results are collated into a PDF report, and both raw and processed data are archived.

Although currently tuned for specific presses with dominant frequencies below 1 Hz, the monitoring system can be adapted to other cyclic machines by adjusting the processing parameters and comfort limits.