Vibration analysis of Storz type firehose couplings

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Abstract. This paper presents the results of an investigation on the effects of the vibrations in the Storz-type firehose couplings. The data processed using a Fast Fourier Transform analyser and a Constant Percentage Bandwidth filter of the vibrations recorded in several couplings are shown. The frequency spectrum analysis of the signals acquired using a “Machine Diagnostics Toolbox”, vibration measurement system, “Pulse”, type 3560, Brüel&Kjær Sound&Vibration. Measurement strongly indicates a connection with the vibration-induced, complex fretting process, that occurs in the stress-concentration areas, leads to the nucleation and growth of micro-cracks and ultimately to the fracturing of the couplings’ lugs.

1. Introduction

1.1. General presentation and background

This research is part of an investigation on the breaking of the Storz type firehose couplings, used by the Romanian firefighters. During firefighting operations, fire hoses are connected to the fire truck or to the hydrants with couplings. When needed, hose lines can be extended with couplings which make these components very important parts of fire control operations.

The Storz type couplings ensure the connection of two parts by interlocking lugs and flanges then rotating these with a quarter of a turn.

A Storz coupling in operating position is shown in figure 1, and a detail of a coupling between two hose sections is shown in figure 2.

![Figure 1. Storz coupling in operating position](image-url)

1- body with hooking lugs
2- pipe/tail piece
3- safety ring
4- sealing ring/gasket

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The damaging of the couplings leads to serious delays in the fire extinguishing actions and may have important effects on the outcome of these operations.

Table 1. Romanian dimensional standards for Storz couplings [1]

| Type | A  | B  | C  | D  |
|------|----|----|----|----|
| Diameter [mm] | 96 | 62 | 43 | 18 |
| Mass [kg] | 2.1 | 1.67 | 0.86 | 0.24 |

The Storz couplings used by Romanian firefighters are fabricated from die cast aluminium, more specifically - AlSi5Cu1Mg alloy. The alloy’s chemical composition, according to [2] and [3], is given in table 2.

Table 2. Chemical composition of AlSi5Cu1 alloy [2], [3]

| Chemical composition [%] | Impurities [%] |
|--------------------------|----------------|
| Cu | Si | Mg | Mn | Al | Fe | Zn | Pb | Ni |
| 1-1.5 | 5-6 | 0.3-0.6 | 0.2-0.5 | rest | 0.8 | 0.5 | 0.2 | 0.3 |

One of the most common and potentially dangerous damages sustained by these couplings during firefighting operations is breaking of the hooking lugs. One example is presented in figure 3.

Figure 2. Two hose sections with Storz coupling

Figure 3. Storz coupling with a broken lug
The authors’ hypothesis is that this type of damage appears mainly due to cracking as a result of microcracks coalescence. The microcracking is thought to appear as an effect of vibration induced fretting wear, occurring in the stress concentration areas of the couplings, during fire extinguishing operations.

The objectives of this research were to acquire data on the vibrations appearing in the couplings, to analyse the spectrum of the vibrations in the couplings, using a Fast Fourier Transform (FFT) analyser and a Constant Percentage Bandwidth (CPB) filter, to identify the frequencies of maximum magnitude, in terms of Power Spectral Density, and investigate the correlation with vibration induced fretting wear and fatigue.

1.2. Research literature review
The vibration frequency effects on fretting wear was initially investigated for different steel types [4]. The research showed an increase of debris at low frequencies, less than 1Hz, for a given number of fretting cycles and displacement amplitudes.

Researches aimed at accelerating fretting tests for steel specimens showed an increase in fretting wear in the frequency range of 102Hz-2,104Hz [5].

Investigations on steel behaviour at partial slip and low amplitude displacement fretting conditions indicated that maximum wear occurred at frequencies in the range of 100Hz-300Hz [6]. Similar work has been done for several pure metals, including iron, copper and aluminium, with specimens subjected to constant amplitude loading scheme and variable frequencies, of 10, 60 and 80 Hz in variable humidity conditions [7].

For aluminium, maximum wear appeared at 60Hz, for normal loading, in the range of 105 fretting cycles and 2% relative humidity in the contact [7].

For other alloys, such as Al7075-T6, European standard EN AW-7075, it was found that the maximum fretting wear for cyclic normal load occurred at a frequency of 1Hz [8]. Research on more advanced alloys, such as Ti-6A1-4V, showed a decrease of fretting fatigue life for combined high-cycle fatigue/low-cycle fatigue testing at 200Hz [9].

Another study, on the 2024-T4 aluminium alloy, European standard EN AW-2024, crack nucleation and failure in specimens at frequencies in the range of 100-350Hz [10]. The effects of frequency variations, of phase difference between normal and tangential vibrations on fretting wear and fatigue has not been extensively studied [11].

Though earlier research results seemed to indicate a decrease in fretting wear rate at higher frequencies, the literature review conclusion is that significant wear, crack nucleation and failure of specimens were observed at frequencies in the range of 1-350Hz. This is due to the specific designs of the experiments, that were conducted on pure metals and alloys, with a wide range of different parameters such frequency, humidity, temperature, number of cycles, displacement amplitude and loading.

Therefore, we can infer with a high degree of confidence, that frequencies between 1-350Hz are an important factor in increasing the fretting wear.

2. Methodologies

2.1. Experimental setup presentation
The experimental setup schematic, presented in figure 4, consists of a fire engine, two hose lines, first of which is connected to the fire engines ‘pump with a Storz coupling and the second hose that extends the first one using a coupling of the same type. The second hose line is connected through another similar coupling to a nozzle.

Data was acquired with a Vibration Analysis System- VAS. The system used was a “Machine Diagnostics Toolbox”, Brüel&Kjaer PulseTM 9727, based on the “Pulse” 3560 multi analyser, with the 7910 software bundle installed.
The system used allows multichannel real time simultaneous Fast Fourier Transform (FFT) and 1/n octave, e.g. Constant Percentage Bandwidth (CPB) spectrum analysis, for vibration diagnostics. The CPB filter used was at 1/12 octave. The data were acquired through four channels, from four sensors, placed consecutively on each of the couplings. The schematic of sensor placing is shown in figure 5.

The sensors used were one ISOTRON accelerometer, IEPE TEDS ENDEVCO type, 752A12 model, sensitivity of 97.74mV/g at 100Hz or 9.967mV/m/s² at 100 Hz and transverse sensitivity of 5%, one ISOTRON accelerometer, IEPE TEDS ENDEVCO type, 752A12 model, sensitivity of 100.6mV/g at 100Hz or 10.26 mV/m/s2 at 100 deHz and transverse sensitivity of 0.5%, one I-TEDE NDVCO type accelerometer, 752A12 model, sensitivity of 107.6mV/g at 100Hz or 10.98mV/m/s² at 100Hz and transverse sensitivity of 1% and one I-TEDE NDVCO type accelerometer, 752A12 model, sensitivity of 107.4mV/g at 100Hz or 10.95mV/m/s2 at 100Hz and transverse sensitivity of 0.8%.

The fire engine- FE used was APCAR 12215 type. Though outdated, it is still widely used, mainly for its 9000 litre water tank.

The fire engine is fitted with the PSI 50/8 centrifugal pump, that allows flows up to 5000 l/min, and working pressures up to 23 bar. PSI 50/8 pump characteristic curves are shown in figure 6.

The hoses were regular 20 m lines, fitted with “C” type Storz couplings. The first line was connected to the fire engine. The second line was connected with a variable flow nozzle- N, as shown in figure 4, TURA-P SF 225 type. To discharge the water, a 1000 litre tank- WT, as shown in figure 4, was used.
2.2. Experimental process and data acquisition details

The data acquisition and processing flow was designed around the “Machine Diagnostics Toolbox”, Brüel&Kjær PulseTM 9727 vibration analysis system’s capabilities.

To acquire the data, three series of in-situ measurements, one for each of the couplings, were designed. To ensure that measurements are taken in conditions as close to real working parameters as possible, each series consisted of four runs of the fire engine’s pump, at working pressures of 2.5 bar, 5 bar, 7.5 bar and 10 bar.

The duration of the runs was chosen at 20 seconds, for practical reasons, i.e. to allow the system to acquire the data needed for the signal processing and avoid the overload of the analyser’s hard drive. The data processing flowchart is shown in figure 7.

![Figure 7. Data processing flowchart](image)

**Figure 6.** PSI 50/8 pump characteristic curves

**Figure 7.** Data processing flowchart
The functional block diagram of the experiment is shown in figure 8.

![Functional Diagram](image)

**Figure 8.** Functional diagram of the experiment

3. Results
Due to the extent of the data, only the spectrums obtained at 2.5bar for the first coupling will be shown in graphic format. The rest of the data will be shown in numerical format, and discussed in correlation with the aforementioned results.

The FFT processing results for the signals acquired in the first coupling, the one that connects the first hose line with the fire engine’s pump, are shown in figure 8, figure 9, figure 10 and figure 11.

**Figure 8.** FFT spectrum for sensor 1, coupling 1, at 2.5bar

**Figure 9.** FFT spectrum for sensor 4, coupling 1, at 2.5bar
Most of the signals. Most of the signals.

The FFT analyzer identified the frequencies for the peak PSD values of the acquired signals. Most of them were found to be in the range of 1Hz to 350Hz, described in the research literature review as a domain of vibrations that increase the fretting wear. A number of these frequencies were in the 400Hz-450Hz range, with one “spike” at 721.6Hz, for the coupling connecting the second hose and the nozzle, measured at a pressure of 10 bar. This can be attributed to a resonance effect, occurring as a result of the operating conditions during in-situ measurements.

The CPB filter processing of the vibrations recorded in the three couplings also indicated a predominance of the frequencies in the range of 1Hz to 350Hz, with a number of them in the range of 400Hz-500Hz. A very high “peak” was found at 917.3Hz. This can be also attributed to a resonance resulting from the operating conditions.

The results showed that the frequencies that carry the most energy, found at maximum values of the PSD identified by the FFT and CPB analysis are in the vibration range of 1Hz to 350Hz, thus indicating that the investigated couplings are prone to damage through fretting wear and fatigue. This strongly indicates that fretting is one of the main factors in the damaging of the Storz type couplings, described by the authors in previous works.

4. Conclusions

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