ACOUSTIC FIREFIGHTING METHOD ON THE BASIS OF EUROPEAN RESEARCH: A REVIEW

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Abstract: In the past few years, there has been a search for new flame extinguishing methods that are both cost-effective and environmentally friendly. This article presents a detailed analysis of contemporary techniques for suppressing flames, including the use of fire-resistant materials, traditional firefighting agents, and eco-friendly acoustic firefighting. Among these methods, the acoustic approach seems particularly promising. The submitted contribution is the review article on a lesser-known firefighting method, especially the acoustic method. Unlike chemical products, acoustic waves are safe for the environment, making them an attractive option for extinguishing flames. The article focuses on using acoustic waves to put out fires, taking into account the wave parameters and components. The effectiveness of this method is evaluated and compared to other techniques.

Keywords: Acoustic Extinguisher; Acoustic Firefighting; Electrical Engineering; Flame Extinguishing; Fire-Resistant Materials; Fire Suppression.

1. Introduction

The fires in Central and Eastern Europe have been a major environmental concern in recent years. They have caused significant damage to manufacturing plants, forests, agricultural land, and human settlements. In the last ten years, the FAO (Food and Agriculture Organization of the United Nations) has highlighted the significance of the issue of fires and has called for increased efforts to prevent them. The causes of these fires are varied, including dry weather conditions and human negligence. Efforts to prevent and control fires have been intensified in recent years, with increased investment in fire detection systems, firefighting equipment, and public awareness campaigns. However, more needs to be done to address the root causes of these fires and reduce their devastating impact on the environment and communities in the region. There are now a variety of new technologies available for detecting and quickly putting out fires [1–3]. Therefore, it is essential to conduct research into the causes of fires, how to detect them, and how to put them out [4–6]. The effects of fires necessitate the exploration of new, environmentally friendly methods of flame detection and extinguishing. The issue is complex because there are many methods and techniques, but no technology is fully universal and practically applied. To this end, a number of research and academic institutions are conducting research into advanced detection techniques, such as using computer vision for rapid identification, and novel methods for extinguishing flames [1–3]. This can be advantageous in minimizing the destruction that fires can cause [4].

This is important because fires have been reported not only in Mediterranean countries such as France, Greece, Portugal and Spain, but also in other parts of the world, such as Australia, Canada and Russia in recent years [7]. In 2020, several countries, including Bulgaria, Poland, Romania, and Ukraine, reported an unusually high number of fires, resulting in the destruction of thousands of hectares of forested land. The fires have also led to air pollution, causing respiratory problems for local residents. The severity of the issue is demonstrated by several incidents worldwide, including fires in Australia, Russia, and the United States that resulted in deaths, homelessness, and property damage [4, 8]. The scope of the problem is also evident by the large areas of vegetation annually burned by fires, estimated to be up to 10,000 km^2 in Europe and up to 100,000 km^2 in North America and Russia [4, 9]. In addition to the direct damage caused by the fires, the long-term ecological impact of these disasters can be significant.

In light of global research, some research conducted in Europe focused on the use of high-power acoustic extinguishers to extinguish flames originating from gaseous fuels and liquids. Because of the limitations, this issue was specifically addressed in this article. The works were carried out in open spaces where the amount of oxygen is high. In addition to unmodulated waves, extinguishing was also performed using low-frequency modulated waves (scientific novelty). This is important because oxygen reacts with most materials. The higher the oxygen concentration in the atmosphere, the more violent the combustion reaction will be or the more intense the fire will be. Higher oxygen concentration also translates into lower ignition temperature and ignition energy required to induce combustion reactions, which are undesirable factors. Moreover, the flame temperature is then higher and thus the destructive capacity of the flame is greater than when the oxygen concentration in the atmospheric air is low.

2. Materials and Methods

In practice, the multifaceted subject of the research necessitates the use of several research methods. The usefulness of each method will be assessed through the prism of its use to achieve specific research objectives. In developing the conceptual approach, elements of system analysis will be applied. The application of this method will contribute to the emergence of a specific structure of the studied problem. To present engineering, technical and environmental aspects of firefighting, the method of individual cases will be applied in addition to the method of literature review, namely, analytical methods, use of modeling and predictive methods, scientific experiment methods. Due to the research character of the project, the comparative method – helpful in the comparative analysis of the obtained results and the institutional-legal method – some fire protection agents are withdrawn from circulation due to their toxicity will also be used.

The article is divided into several parts. The first contains information on the various approaches to fighting fires. In this regard, the first priority should of course be to ensure that the fire never breaks out. At this point, non-combustible/fire-resistant materials come to the fore. Next, traditional fire prevention strategies (such as water, sand, fire blankets, hydronets, and fire hooks) as well as environmentally friendly firefighting techniques utilizing acoustic waves are discussed. The next section discusses acoustic methods due to practical conditions (acoustic wave parameters and components), as well as different applications of low-frequency waves. Acoustic firefighting is a promising and environmentally friendly method of suppressing flames. The paper deals with fire extinguishing, taking into account an analysis of the possibility of using acoustic waves to extinguish flames. Taking into account the topic of the article, environmentally friendly flame extinguishing, it focuses especially on the acoustic methods. In recent years, there has been a growing interest in this technique, and research in Central and Eastern Europe has contributed significantly to its development. This review article summarizes the current state of research on acoustic firefighting method. In practice, there are not many works published on the use of acoustic technologies to extinguish flames – so the state of the art is described based on the existing solution that may be equipped with an intelligent module. This is an original approach that makes it possible to extinguish flames using acoustic waves generated by a high- and very high-power acoustic extinguisher working at low frequencies. The paper ends with a brief summary containing limitations in conclusions.

3. Flame Resistive Materials

Flame retardant materials can be defined as non-combustible materials that resist combustion. These materials are either non-combustible materials due to their natural structure (intrinsically flame retardant) or non-combustible materials that become fire resistant by adding various additives or undergoing various processes (extrinsically flame retardant). It would not be wrong to say that these materials, which have been very popular in the last decades, have actually been used since ancient times. Indeed, research shows that; Prior civilizations, despite their limited knowledge of physics and chemistry, found ways to create flame retardant materials [10]. In fact, research into taming fire shows that centuries ago the Chinese were seen as the first innovative solutions. To prevent the fire from spreading, they covered the wood with vinegar and alum before covering it with clay [11]. This was a tactic copied by the Romans thousands of years later to protect the Empire's boats [12]. This tried-and-proven method was still being copied by theater owners in England in the 16th century, and a mixture of alum, ammonium, and clay was applied to fabric stage curtains to reduce the risk of ignition. In fact, alum is still used today in fire extinguishers to put out chemical and oil fires. The Great Fire of London in 1666 could have been far more devastating, the screed is known to work and to be quite effective at stopping fires. The first scientific attempt to make fire retardant materials took place in the 19th century, when our understanding of chemistry improved [13]. In 1821, Frenchman Joseph Louis Gay-Lussac formulated the law stating that if the mass and volume of a gas are kept constant, the gas pressure increases linearly as temperature increases [13–14]. Although other chemists such as William Perkins, who added tin oxide to the mix in 1912, continued their research, the real breakthrough in fire resistance research actually came in the late 1900s. The most common flame retardant polymers in the 1970s were unsaturated polyesters and thermosets such as epoxy resins. These thermosets contain reactive halogen compounds and aluminum hydrate as additives to impart flame retardant properties. Phosphate esters have also been used as flame retardant additives in plasticized polyvinyl chloride, cellulose acetate film, unsaturated polyesters and modified polyphenylene oxide [10]. The use of halogen-containing flame retardant additives was much less than the use of the additives mentioned in the 1970s. When looking at such additives, substances such as polychlorinate, dibromopril phosphate, brominated aromatics, pentabromochlorocyclohexane, hexabromocyclodocan are seen. Subsequently, many new brominated additives and a number of chlorinated products entered the market [15–16].

With the widespread use of thermosets and thermoplastics in large-scale applications and the introduction of stricter safety regulations, new flame retardant systems have been developed. These systems consist of boron, aluminum, phosphorus, antimony, chlorine and bromine. Although halogenated flame retardants are widely used in polymers due to some advantages such as low loading and good mechanical properties, their effects such as poor compatibility and high volatility sometimes cause performance loss [16–19].

More importantly, various harmful effects of halogens began to emerge in the following years. The high amount of carbon monoxide (CO) and smoke released while the fire retardant mechanism is operating has limited the use of these materials. So much so that some environmental activist organizations have had propaganda claiming that halogenated systems, especially brominated systems, play a significant role in the increasing percentage of people dying from smoke inhalation in North America, and their use is banned in some countries [10]. A real fire contains many poisonous gases. The most serious is carbon monoxide, CO, a highly toxic and non-irritating gas. CO can immediately disrupt the respiratory process, as it prevents the blood from carrying oxygen [17].

The use of inorganic minerals, which are considered as an alternative to halogens, is not only safer but also very effective in terms of providing fire resistance. Commonly used materials in this regard mostly contain metal hydroxide in their structures. Metal hydroxides first decompose endothermically and release water. Endothermic decomposition serves to remove heat from the surrounding of the flame, thereby cooling the flame. As a result of this acidification, the pyrrolsis decreases in the condensed phase. The release of water dilutes the amount of oxygen that can enter the flame and prevents the critical fuel/oxygen ratio (physical effect in the gas phase). Both mechanisms combat ignition. Also, after decomposition, a ceramic-based protective layer is formed, which improves the insulation (physical effect in the dense phase) and leads to the smoke suppression effect (chemical effect in the dense phase). The ceramic-based protective layer provides effective protection of the material during combustion, leading to a significant reduction in heat release [17–19]. Considering the inorganic minerals used in this field, the commonly used ones can be listed as follows: Aluminum Trihydrate (2Al(OH)3), Magnesium Hydroxide (Mg(OH)2), Huntite (Mg3Ca(CO3)4), Hydromagnesite (Mg4(CO3)3(OH)2.3H2O), Boehmite, AlO(OH), Calcium Sulphate Dihydrate, Gypsum (CaSO).

4. Classical Firefighting Agents

Flames can be extinguished with a variety of extinguishing agents. To extinguish flames in the first phase of formation, so-called handy extinguishing agents are used, in particular: water, sand, fire blankets, hydronets, and fire hooks. The use of water and sand, although natural materials and do not degrade the environment, damages the elements of the fixture. The use of a fire blanket poses a safety risk to firefighters. The possibilities of applying hydronets and fire hooks are also severely limited. Therefore, firefighting products are mainly based on the use of chemicals that are harmful to the environment and firefighters. Due to the convenience of use, typical fire extinguishers are most often applied, which are selected depending on the type of fire.

If the burning material is an organic solid that is characterized by glowing when burned (e.g., wood, coal), then water, firefighting foams, extinguishing powders, water mist, and carbon dioxide are used to extinguish the flames. If the burning material is flammable liquids and solids, which are characterized by the fact that the melting process occurs due to the heat produced during the fire (e.g., kerosene, paraffin, gasoline, tar, melting plastic), then extinguishing foams, extinguishing powders, carbon dioxide, and halons may be applied. If the burning material is flammable gases (e.g., acetylene, methane, natural gas, propane, butane), halons and extinguishing powders can be used for extinguishing. If the burning material is combustible metals (e.g., magnesium or uranium), properly selected extinguishing powders are used for extinguishing. Halon fire extinguishers, carbon dioxide, and extinguishing powders are also applied to extinguish flames that occur within electrically powered equipment. However, in recent years, halon fire extinguishers, effective in firefighting actions, although dangerous to health, have been replaced by pure fire extinguishers, which consist, according to the NFPA (National Fire Protection Association) standards, of properly selected extinguishing gases such as halogenated hydrocarbons and inert gases [20–21]. This is related to the toxic effects of halon fire extinguishers on the environment and human health.

The key issue when selecting an extinguishing agent is to ensure that the loss caused by the extinguishing does not exceed the loss resulting from the fire. A disadvantage of traditional foam extinguishers is that they cannot be turned off before the extinguishing agent is exhausted. In turn, the use of powder extinguishers produces dust in the space.

Water is an electrolyte and conducts electricity, which could result in an electric shock to the person extinguishing the flames (the use of water mist then comes to the aid). It is also important to remember that it is prohibited to extinguish electrically powered equipment and metals with water and foam extinguishers. Water cannot also be applied to extinguish flames caused by fats and oils.

There are certain rules to follow when extinguishing flames. It is recommended that the extinguishing agent be directed from the edge of the fire to the center of the burning material. On the other hand, if you are extinguishing materials that are vertically positioned, it is recommended that the extinguishing agent be directed from the top to the bottom of the material being extinguished.

The inconvenience of using typical fire extinguishers is mainly due to their short operating time and the fact that it is no possibility to quickly fill the tank to use the same extinguisher repeatedly at the site of a fire. This issue is so important that the search for new ways to detect and fight fires has been started.

5. Environmentally Friendly Acoustic Firefighting

For a fire to occur, three factors are required to be present at the same time: a fuel (a combustible material, such as a gas), an oxidizer (such as air containing oxygen) and a source of heat energy (a fire source). According to the combustion triangle, the absence of any of these components will result in the extinguishing of the flames. Knowledge of this fact is used to develop a variety of flame extinguishing techniques.

The acoustic method of extinguishing is based on the use of the movement of air particles created by the generation of acoustic waves from sound sources with high acoustic power. Ongoing research has shown that basses have very good extinguishing properties. Due to their features, they can reach potentially inaccessible areas. In practice, the emission of an acoustic wave of a certain frequency and acoustic power affects the vibrations of air molecules, which are produced by converting the mechanical energy of the sound source into acoustic energy. Changes in pressure (local compaction and dilution of air molecules) at a sufficient level of its turbulence result in breaking (splitting into parts) of the flame when the critical frequency value is reached. The waving motion of the particles further affects the temperature, which decreases. If the temperature of the stripped part of the flame is less than the ignition temperature, a condition of flame extinguishing will occur. Observations show that the sound wave by increasing the speed of air movement at the edge of the flames causes a reduction in the area where the combustion process takes place, which is a favorable phenomenon [5]. The higher evaporation of the fuel brings about the expansion of the flame and lowers its overall temperature. Since the same amount of heat is distributed over a larger area, combustion is disrupted. It is easier to extinguish a detached, deflected flame as a result of it being torn apart by the propagation of acoustic waves than an undisturbed primary flame. The continued emission of acoustic waves to the flame source results in complete extinguishment of the flame. Fig. 1 shows a scheme of the physical principle of flame extinguishing with the use of acoustic waves. This technique can also be applied to control flames (surface disturbances).

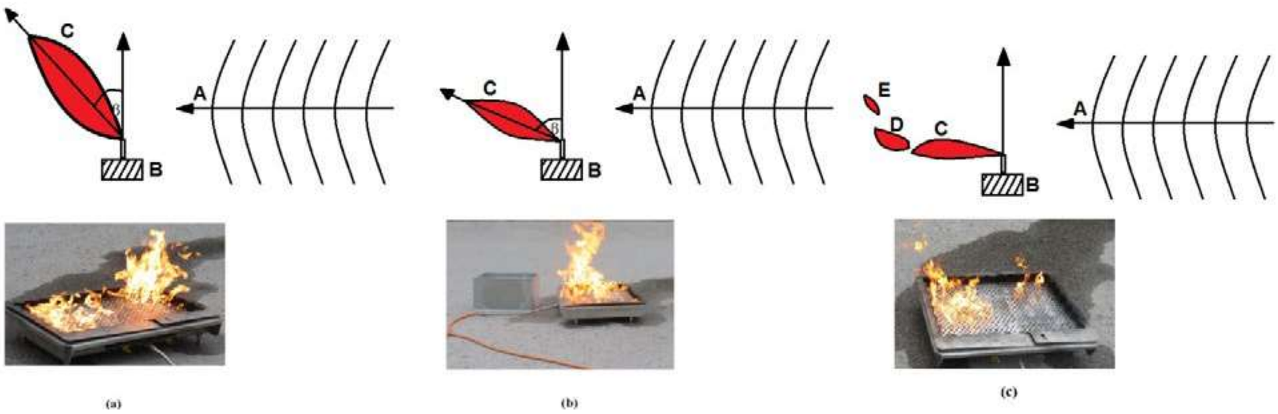

Figure 1. Scheme of the physical principle of flame extinguishing by acoustic waves at the terminal acoustic power (constant), where: A – direction of propagation of the acoustic waves; B – source of flames; C – flame; D – combustible mixture (illustration of flame rupture); E – exhaust fumes and combustible mixture; (a) at a wave frequency different from the critical frequency; (b) at a wave frequency close to the critical frequency; (c) first, at a wave frequency equal to the critical frequency, the exhaust fumes are separated from the combustible mixture (flame), then the flame is broken (the combustible mixture is separated from the flame).

Many advantages of acoustic technique can be distinguished, but also some limitations. Since sound waves pass through a variety of materials (solid, liquid, and gas), this is an asset. Furthermore, they are not a chemical product and do not pollute the environment like chemical extinguishing agents. When acoustic waves are applied, no dirt remains on the extinguished materials and no toxic gases are emitted. The use of acoustic waves and artificial intelligence makes it possible to extinguish flames in an environmentally safe way as soon as they appear (firebreak), without time delay or human intervention. Today, this technique may provide an alternative to fire extinguishers that allow the extinguishing of flames of liquids and gases. In the case of solids, the inconvenient fact is that heat cannot be extracted from inside the material, which limits the use of this technology.

Based on a review of the literature, the last documented attempts to extinguish flames using acoustic waves were reported in Europe in the 1990s. The results are a few publications and patents [22–23]. Research to analyze the extinguishing capabilities of acoustic waves was also conducted by the U.S. agency DARPA since 2008. [24]. One year earlier, the 'Myth Busters' proved that flames can be extinguished with a human voice. However, the required sound pressure to extinguish the fire exceeded the human ear pain threshold and this method was disqualified from a practical use [25]. This topic was continued in Europe (in Poland) since 2010 under a grant co-financed by the Ministry of Science and Higher Education from the program 'Innovation Incubator +' [26–27]. The tangible results of the work are four solutions submitted to the Patent Office, which have already received protection [28–31]. In light of global research, the high-power acoustic extinguisher was designed and used.

Acoustic waves have been shown to be applied to extinguish flames originating from burning gases [32] and liquids [33]. As proven in Poland, both modulated and unmodulated waves can be used for extinguishing [e.g., 5, 34–35]. Methods familiar from mathematics can be used to analyze technology boundary values to some extent [36]. A new feature is the demonstration of the ability to use modulated waves to extinguish flames. In Europe, research in this area is in progress. The extinguisher can generate a directional acoustic stream of different frequencies, selected according to the source of the flames. Information on acoustic methods is presented in the next section.

6. Acoustic Wave Parameters and Technical Components

As mentioned earlier, the extinguishing effects depend, among other things, not only on the burning material but also on the acoustic wave parameters and the components of the device for extinguishing flames with acoustic waves (acoustic extinguisher). Few publications in this area (there are not many in the literature) are presented below, based on the analysis of the literature review. From this it is possible to become familiar with the methods of extinguishing flames using acoustic waves. It should be emphasized that such an extinguisher can be equipped with artificial intelligence systems (not necessarily dedicated to embedded systems, as in our case) and based on other solutions. The effect is a smart acoustic fire extinguisher.

The use of low-frequency waves (below 100 Hz) has been shown in many studies to have a beneficial effect on the rate of combustion [33, 37–38]. This process can occur in a discontinuous manner [39–40]. Flow disturbances are important (the mean flow effect is a causal factor) [32]. Based on the studies of Chen and Zhang [41] and Niegodajew et al. [32], the mean flow effect is independent of the excitation frequency. Its value increases with increasing pressure. In practice, the flame follows the fuel flow until it separates from the burner outlet. Only when a critical pressure level is reached, the flame is interrupted. The action of acoustic waves on the flame causes it to deform, break into pieces, disperse, and then extinguish. It is important to determine the minimum sound pressure level at which the extinguishing effect is achieved. Not without significance is the inertia of the flame [43]. Flame extension results in an increase in emitted heat until the flammability limit is exceeded [42–44]. The rupture of the flame stream due to bombardment by acoustic waves was described in [40]. Flame wrinkling was presented in [45–46] and its bifurcation in the articles: [47–48]. In practice, a thin (long) flame is easier to extinguish than a wide flame [49].

The paper [42] provides information on diffusion flame extinguishing with critical frequency value and sound power. The flame extinguishing process was visualized by using a streak apparatus. In turn, the article [32] analyzes the extinguishing properties of low-frequency acoustic waves for different burner powers and flame distances from the extinguisher output.

The paper [34] presents the results of a research on the effect of acoustic pressure on the flame extinguishing process for a stepwise varying distance from the device output, for multiple frequencies. A fire extinguisher was applied to extinguish the flames, which generated an appropriately directed acoustic stream. High efficiencies were reported, especially for low frequencies. In this paper, numerous experiments showed that there is an inverse relationship between increasing the distance from the device output and decreasing the sound pressure level. In practice, it is possible to extinguish flames using low-frequency waves that are different from the frequency at which the minimum acoustic impedance value was observed. However, the frequency mismatch results in significant vibration of the sound source diaphragm due to loudspeaker design limitations. Increasing the frequency is recorded to increase the electrical power that must be delivered to the sound source to observe a fire-extinguishing effect. Acoustic waves of varying frequencies can also be used for extinguishing, which can be crucial for the suppression of flames whose sources are different types of fuels and materials [35].

Moreover, additional screens can be used for flame extinguishing. The results of a research on the effect of an acoustic screen (single obstacle model) on flame extinction are found in the article [21]. To maximize the validity of the results obtained, each experiment was repeated three times. For this purpose, the acoustic pressure required to extinguish the flames was determined and the acoustic field between the screen and the output of the acoustic extinguisher was analyzed. The largest range of pressure changes was observed at a slight distance from the screen. This research highlights that the immediate environment can affect the flame extinguishing process [21].

The high-power acoustic extinguisher, in which we continue work, is shown in Fig. 2.

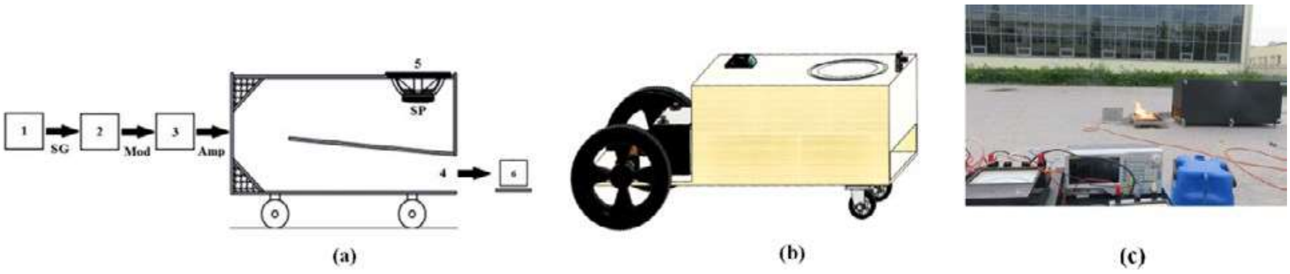

Figure 2. (a) Components of the high-power acoustic extinguisher: 1 – generator (SG); 2 – modulator (Mod); 3 – power amplifier (Amp); 4 – output of the extinguisher (Out); 5 – sound source (SP); 6 – flame source (FL); (b) Prototype of the high-power acoustic extinguisher (a simplified 3D model); (c) The actual high-power acoustic extinguisher which is used for environmentally friendly research.

The acoustic extinguisher presented in Fig. 2 consists of: a signal generator, a modulator, an amplifier, a sound source as a woofer, a waveguide, and cabling [34]. For measuring, the electrical quantities and sound meters are also equipped. This acoustic extinguisher is capable of extinguishing flames from both liquid and gaseous fuels. Waves of varying frequencies can be used for extinguishing purposes. In general, the waveguide may have a rectangular, circular, exponential, or conical cross section. When tube resonators are applied, the cross-sectional dimensions are much smaller than the wavelengths amplified by the resonance phenomenon. Additionally, the use of a diaphragm at the extinguisher output enables a local increase in

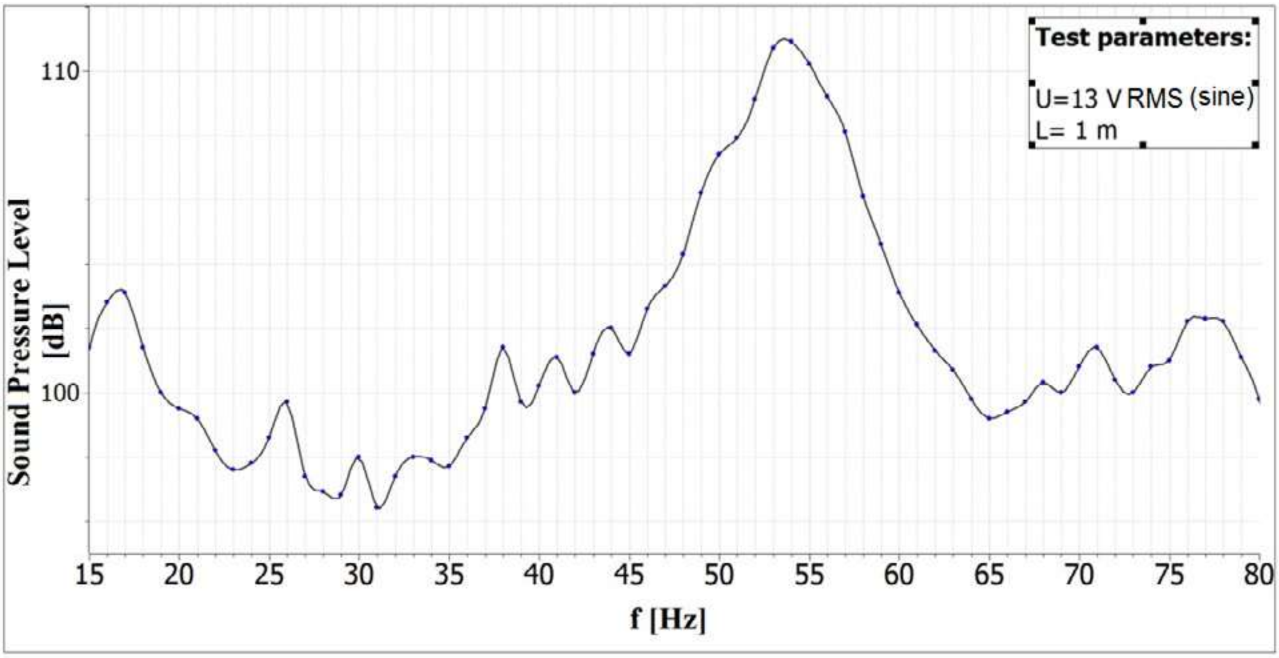

Figure 3. Sound pressure level as a function of frequency.

sound pressure with a reduced device output diameter. Due to practical considerations (smaller waveguide length), waveguides with a closed end are applied, which reduces their size and thus translates into the size of the device for extinguishing flames with acoustic waves. As mentioned previously, the acoustic extinguishing methods are based on the use of low-frequency acoustic waves that are difficult to suppress and reach places that are difficult to reach. Such waves pass through solids, liquids, and gases. It is crucial to apply high-power extinguishers so that flames can be extinguished at a greater distance from the extinguisher output.

For frequency selection, a diagram of sound pressure level as a function of frequency at a distance of 1 m from the extinguisher output is presented *(L=constant)*. Fig. 3 shows a diagram in which the frequency was varied from 15 Hz to 80 Hz in 1 Hz increments. Since the minimum impedance of the acoustic extinguisher (11.4 Ω) was obtained for 17.25 Hz, this frequency is taken as the operating frequency of the acoustic extinguisher [34]. Based on an analysis of Fig. 3, it can be seen that at this frequency the maximum sound pressure level is 103.1 dB, which proves that the selection of the frequency is reasonable considering the mechanical load on the diaphragm of the sound source and the acoustic efficiency.

To determine as precisely as possible the sound pressure level at which the extinguishing effect is observed, a point source of flames was used, which was a candle placed 0.5 m behind the extinguisher output *(L=constant)*. The acoustic extinguisher presented in Fig. 2 was equipped with a 1700-watt sound source (nominal power). The experiments were conducted in a free space under windless conditions (see Tab. 1). SVAN 979 sound level meter was applied for measurements.

Table 1. Overview table of the required sound pressure level specific values to extinguish flames depending on the frequency.

f [Hz]	Sound Pressure Level [dB]
16	121.4
18	121.9
20	125.2

The frequencies for which the results are presented (16, 18 and 20 Hz) were chosen in a non-accidental way (they are close to the operating frequency of the acoustic extinguisher). By analyzing the data in Tab. 1, it can be observed that the minimum sound pressure level required to extinguish the flames is between 120 dB and 130 dB.

7. Smart acoustic extinguisher

As part of the authors' contribution to the prototype fire extinguisher presented in Fig. 2, a system has been developed using artificial intelligence that can detect flames, which are then extinguished using acoustic technology. It is possible to combine the detection with its usage in acoustic fire extinguisher [e.g., 5, 35, 50–52]. A collaboration is ongoing in this area. The authors use DNN (Deep Neural Networks) and SSD MobileNet and MASK R-CNN models, which are characterized by good performance in embedded systems. It is worth noting that during the research conducted by the authors, other models were also tested, modified neural networks, and applied transfer learning. The results showed that the two models, SSD MobileNet and MASK R-CNN, are best suited for this task (depending on the speed and accuracy of image recognition). These models were trained on pictures preprocessed using scaling, rotating, and translation operations. In addition, the training batch was enlarged by using operations to change brightness. 5,000 images were used for training. Our test results are 79% accuracy for SSD MobileNet and 96% for MASK R-CNN. Such robotic – autonomous fire extinguishers capable of automatically detecting flames and extinguishing them may find practical applications (expenses for emergency management are increasing) [53–56]. The systems can use various means of communication to transmit data from remote locations [57–61]. Another aspect is the attenuation of radio waves in the Earth's atmosphere, when using wireless communications to transmit from areas where flames have been detected, depending on the designed system [62–64].

8. Conclusions

The use of appropriate substances and materials for fire protection, including enriched with natural additives, is very important from the point of view of the possibility of formation and spread of fires. Therefore, in the future, it can be expected around the world to continue a lot of scientific research also in terms of the creation and use of non-combustible materials [65–71], which in the long term can be applied to the construction of components of firefighting equipment operating in a variety of environments, as exemplified by oil refineries [72–76].

The use of acoustic waves appears to be a novel technique for extinguishing flames. This technique may find particular application in extinguishing burning materials that are difficult to extinguish when using classical fire protection measures or when they are unavailable. This is important because acoustic technology can be used in a long-term perspective to extinguish flames from substances whose properties do not allow them to be extinguished by typical chemical means or where access to them is severely limited [75]. Additionally, it can be used to extinguish flames in areas that are difficult to access. However, the effectiveness of acoustic method is highly dependent on the specific parameters of the waves generated. Furthermore, recent research shows that systems that use artificial intelligence and acoustic technology may coexist [35]. However, to realize the potential of the technology, further research is needed to accurately determine the extinguishing capabilities of acoustic waves (the technology is currently in the testing and development phase, and works are necessary to increase its operating range if this technology is to be used in open space), including also research on the effects of acoustic waves on human health, which is especially important if this technique is applied in the presence of humans. In practice, the effect of acoustic waves on human health depends on the sound pressure level and the wave frequency. It is assumed that a person should not be exposed to sound pressure above 110 dB (pain threshold) and waves with a frequency below 16 Hz (infrasound) [77]. Exposure to sound waves may lead to headaches, vibroacoustic disease and general fatigue. Therefore, the use of protective items and equipment, including hearing protectors, is recommended at all times. Furthermore, the use of high-intensity sound waves can cause damage to nearby structures. Since this technique requires a lot of research and its possibilities are still being explored, its use in the presence of humans is currently discouraged. It is assumed that sound sources can be permanently installed, for example, in the foundations or structure of the device in question. Since acoustic waves are not a chemical product, they do not pollute the environment. The acoustic system can be activated automatically when flames are detected by classical or smart sensors [78], as described in the article, and extinguish the flames until they are completely extinguished (unlimited operation time, restricted only by the acoustic extinguisher's access to battery or mains power). Since the arrival of the relevant services and the use of traditional extinguishing agents by humans take time and any delay in extinguishing the flames involves risk to life and financial loss, the advantage of acoustic technology is that it can quickly and environmentally friendly extinguish the flames without human intervention.

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DREADNOUGHT GUITAR TOP PLATE INNOVATION

Ondřej Jirásek, Pavel Hoffman

Abstract: This paper describes the innovation of Dreadnought guitars, especially braces on top plate. The goal was to increase the dynamic range of the instruments, not only in strength but also in spectral spread. The prolongation of tones in the Sustain and Release phases was also important. Mechanical and acoustic properties of instruments from Furch Guitars' production were measured (Chladni figures, frequency response), numerical simulation of innovated top plate in program ANSYS was prepared (by the matrix) and the changes in organisation of ribs were proposed as following. The new samples of innovated Dreadnought guitars were produced by the factory, again measured, analysed and evaluated.

1. Introduction

The goal of the work was the innovation of Dreadnought guitars produced by Furch Guitars. The improvement wasn't just about getting a better timbre of the instrument compared to the competition, but also taking advantage of the construction improvements that the manufacturer has used in other types of its own guitars – for example, the proven braces and the convex tension of the resonant top plate in the OM (Orchestral model) guitars. At the same time, a number of sub-experiments were carried out: investigation of the properties of different resonance wood (for example spruces), different thicknesses of the resonant top plate, changes in the shape of ribs (bracing), differently tensioned and pressure-transmitting strings, etc.

2. Plucking point on the string

The ideal string is an almost perfect oscillator due to its one-dimensional character. When properly excited, it can generate an almost pure harmonic spectrum composed from harmonic components. [5] The quality of the spectrum (spectral components, spread, slope, spectral centroid, etc.) depends on the mechanical properties of the string: string diameter, string length, material density, modulus of elasticity, tensile strength, etc. These properties were preserved as constants during the measurements due to using the same strings and the same length instruments from the bridge to the nut (scales length/mensura).

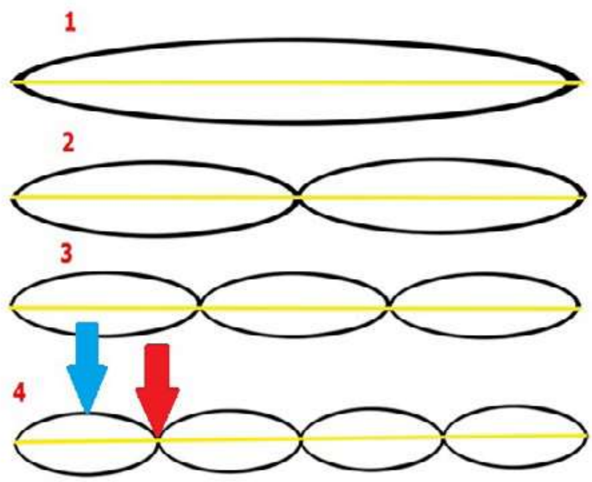

Fig. 1: Plucking into anti-node (desirable-blue arrow) and into node (undesirable-red arrow)

The bigger problem in the measurement stages was to maintain the same excitation – plucking the string as similar as possible. The tones were excited by a guitarist using the same pick, and especially the same place of strumming: about one-ninth of the string