MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
NATIONAL AVIATION UNIVERSITY
Faculty of Aeronautics, Electronics and Telecommunications, Department of Aviation Computer-Integrated Complexes

ACCEPT TO PROTECTION
Head of Department
_____ Viktor SINEGLAZOV
“_”_____2023 y.

QUALIFICATION PAPER (EXPLANATORY NOTE)
HIGHER EDUCATION STUDY

“MASTER”

Specialty 151 "Automation and computer-integrated technologies"
Educational and professional program "Information support and engineering of aviation computer systems"

Subject: Optimal damping system of fire extinguisher liquid

Performer: student of the group I3-225M Bohdan Tykhonov

Supervisor: Senior Lecturer, Oleksandr Hordiienko

Consultant of the "Environmental Protection" section________ Radomska M.M.

Consultant of the "Occupational safety and health" section________Kazhan.K.I.

Norm control:____Fylashkin M.K.

Kyiv 2023

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
Факультет аеронавігації, електроніки та телекомунікацій
Кафедра авіаційних комп’ютерно-інтегрованих комплексів

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач випускової кафедри
________Віктор СИНЄГЛАЗОВ
“__”_____2023 р.

КВАЛІФІКАЦІЙНА РОБОТА (ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ

“МАГІСТР”

Спеціальність 151 «Автоматизація та компю’терно-інтегровані технології»
Освітньо-професійна програма «Інформаційне забезпечення та інженерія авіаційних комп’ютерних система»

Тема: Система оптимального демпфування коливань вогнегасної рідини

Виконавець: студент групи ІЗ-225М Тихонов Богдан Сергійович

Керівник: старший викладач, Гордієнко Олександр Миколайович

Консультант розділу «Охорона навколишнього середовища» _____ Радомська М.М.

Консультант розділу «Охорона праці»_____________________Кажан.К.І.

Нормоконтролер:_______________Філяшкін М.К.

Київ 2023

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ
Факультет аеронавігації, електроніки та телекомунікацій
Кафедра авіаційних комп'ютерно-інтегрованих комплексів

Освітній ступінь: Магістр

Спеціальність: 151 " Автоматизація та комп'ютерно-інтегровані технології"

ЗАТВЕРДЖУЮ

Завідувач кафедри

Віктор СИНЄГЛАЗОВ

“ ____ ” __________2023 р.

ЗАВДАННЯ

на виконання дипломної роботи студента

Тихонова Богдана Сергійовича

1. **Тема проекту (роботи):** “Система оптимального демпфування коливань вогнегасної рідини ”
2. **Термін виконання проекту (роботи):** з 01.12.2023 р. до 27.12.2023 р.
3. **Вихідні данні до проекту (роботи):** моделювання демпфування коливань рідини для циліндричного бака з радіальними перегородками.
4. **Зміст пояснювальної записки (перелік питань, що підлягають розробці):**

   1. Використання авіаційної техніки для боротьби з лісовими пожежами;

   2. Методи боротьби з коливальними процесами;

   3. Розрахунок гідродинамічних сил у баці літака-пожежника;

   4. Система демпфування рідини радіальними перегородками у баці літака-пожежника.

Перелік обов'язкового графічного матеріалу: 1. Методи боротьби з коливальними процесами. 2.Схема випробувань для визначення власних частот і форм коливань вільної поверхні рідини. 3. Профіль форми вільної поверхні при коливанні рідини в циліндрі . 4. Радіальна перегородка, що демпфірує (розташована в баці);

5. Календарний план-графік

№ пор.	Завдання	Термін виконання	Відмітка про виконання
1.	Опис завдання	02.10.2023 – 03.10.2023	
2.	Формування мети та основних завдань оптимізації	03.10.2023 – 05.10.2023	
3.	Аналіз існуючих алгоритмів оптимізації	07.10.2023 – 15.10.2023	
4.	Аналіз проблеми і постановка задачі оптимізації пального при затримках	17.10.2023 – 01.11.2023	
5.	Розробка алгоритму о оптимізіції пального при затримках	01.11.2023 – 15.11.2023	
6.	Розробка програмного забезпечення оптимізіції пального при затримках	20.11.2023 – 05.12.2023	
7.	Оформлення пояснювальної записки	07.12.2023 – 10.12.2023	
8.	Підготовка презентації та роздаткового матеріалу	12.12.2023– 17.12.2023	

6. Консультанти з окремих розділів

Розділ	Консультант (посада, П.І.Б.)	Дата, підпис	
		Завдання видав	Завдання прийняв
Охорона праці	Доцент Катерина КАЖАН		
Охорона навколишнього середовища	Доцент Маргарита РАДОМСЬКА		

7. Дата видачі завдання: “2” жовтня 2023 р.

Керівник дипломної роботи ________ Олександр ГОРДІЄНКО

Завдання прийняв до виконання ________________ Богдан ТИХОНОВ

NATIONAL AVIATION UNIVERSITY
Faculty of aeronavigation, electronics and telecommunications
Department of Aviation Computer Integrated Complexes
Educational level: Master
Specialty: 151 “Automation and computer-integrated technologies”

APPROVED
Head of Department
Viktor SINEGLAZOV
“____” __________2023

TASK
For the student’s thesis
Tykhonov Bohdan Sergiyovych

1. **Theme of the project:** “Optimal damping system of fire extinguisher liquid “
2. **The term of the project (work):** from December 01, 2023 until December 27, 2023
3. **Output data to the project (work):** Identification of fuel optimization solutions for delayed flights.
4. **Contents of the explanatory note (list of questions to be developed):**
   1. In the use of aviation equipment to combat forest fires;
   2. Methods of combating vibrational processes;
   3. Calculation of hydrodynamic forces in the tank of a firefighter;
   4. Fluid damping system with radial partitions in the tank of the firefighter aircraft.

   List of compulsory graphic material: 1. Methods of combating vibrational processes; 2. Test scheme for determining the natural frequencies and forms of oscillations of the free surface of the liquid; 3. Profile of the shape of the free surface when the fluid oscillates in cylinder; 4. Damping radial partition (located in the tank);

5. **Planned schedule:**

№	**Task**	**Execution term**	**Execution mark**
1.	Task description	02.10.2023 – 03.10.2023	
2.	Formation of goals and main tasks of optimization	03.10.2023 – 05.10.2023	
3.	Analysis of existing optimization algorithms	07.10.2023 – 15.10.2023	
4.	Analysis of the problem and setting the problem of fuel optimization with delays	17.10.2023 – 01.11.2023	
5.	Development of an algorithm for fuel optimization during delays	01.11.2023 – 15.11.2023	
6.	Development of fuel optimization software for delays	20.11.2023 – 05.12.2023	
7.	Development of an explanatory note	07.12.2023 – 10.12.2023	
8.	Preparation of presentations and handouts	12.12.2023– 17.12.2023	

6. **Consultants from individual sections**

Section	Consultant	Date, signature	
		Issued the task	Accepted the task
Occupational safety and health	Associate Professor Kateryna KAZHAN		
Environmental protection	Associate Professor Margarita RADOMSKA		

7. **Date of task receiving:** “2” October 2023

Diploma thesis supervisor ________________________ Oleksandr HORDIIENKO
(signature)

Issued task accepted _______________________________Bohdan TYKHONOV
(signature)

РЕФЕРАТ

Пояснювальна записка кваліфікаційної роботи : «Система оптимального демпфування коливань вогнегасної рідини»

СИСТЕМА ДЕМПФУВАННЯ КОЛИВАНЬ, ВОГНЕГАСНА РІДИНА, ОПТИМІЗАЦІЯ СТАБІЛЬНОСТІ, ТОЧНІСТЬ ВИМІРЮВАНЬ.

Предмет дослідження: Розробка системи оптимального демпфування коливань вогнегасної рідини в умовах екстремальних ситуацій.

Мета кваліфікаційної роботи: Створення та імплементація системи, яка забезпечує ефективне демпфування коливань вогнегасної рідини, знижуючи ризик її розливу під час використання.

Метод дослідження: Теоретичний аналіз, моделювання динамічних процесів.

Об'єкт дослідження: Система демпфування коливань вогнегасної рідини в резервуарах.

Основні результати дослідження: Розроблено та випробувано інноваційну систему, яка забезпечує високу ефективність демпфування коливань вогнегасної рідини. Система адаптована для використання в різних умовах, включаючи рухомі об'єкти та об'єкти з підвищеним ризиком пожеж.

Розроблена стратегія технічного захисту: У роботі розроблено стратегію технічного захисту системи, що включає заходи контролю доступу та моніторингу стану обладнання.

Рекомендації та подальші напрями досліджень: Результати дослідження можуть бути застосовані в промисловості та цивільній обороні для підвищення безпеки та ефективності використання вогнегасних систем. Подальші дослідження можуть спрямовуватися на вдосконалення системи для її адаптації до специфічних умов експлуатації.

ABSTRACT

Explanatory Note for the Qualification Work: 'System for Optimal Damping of Firefighting Liquid Oscillations'

SYSTEM OF DAMPING OSCILLATIONS, FIREFIGHTING LIQUID, STABILITY OPTIMIZATION, MEASUREMENT ACCURACY.

Subject of Research: Development of a system for optimal damping of firefighting liquid oscillations in extreme conditions.

Purpose of the Qualification Work: To create and implement a system that provides effective damping of firefighting liquid oscillations, reducing the risk of spillage during use.

Research Method: Theoretical analysis, dynamic process modeling, laboratory testing.

Object of Research: System for damping oscillations of firefighting liquid in tanks.

Main Results of the Research: An innovative system has been developed and tested, providing high efficiency in damping the oscillations of firefighting liquid. The system is adapted for use in various conditions, including mobile objects and objects with an increased risk of fire.

Technical Protection Strategy: The work has developed a strategy for the technical protection of the system, including access control measures and monitoring of equipment status.

Recommendations and Further Research Directions: The results of the research can be applied in industry and civil defense to enhance the safety and efficiency of fire extinguishing systems. Further research can be directed towards improving the system for its adaptation to specific operating conditions.

CONTENTS

CONTRACTION

LA – aircraft

MKR – the method of finite differences

MGE – limit element method

MKE – finite element method

DKSH – angular sensoratitsspeedand

VP – executive drives

ACS – automatic control system

INTRODUCTION

The system of optimal damping of liquid vibrations (sometimes known as an active damping system) can be applied in various fields where it is important to control the oscillations of the liquid. Here are a few examples of such systems' applications: Oil and Gas Industry: The oil and gas industry uses large tanks and pipelines for storing and transporting gases and liquids. The oscillations of the liquid in these systems can be hazardous and lead to leaks or accidents. Optimal damping systems can help reduce these oscillations and ensure safety.

Aerospace Industry: In spacecraft and rockets, liquid rocket fuel is often stored in tanks and can experience vibrations during flight. These vibrations can affect flight stability and accuracy. Optimal damping systems can help mitigate these oscillations. Liquid Energy: In the liquid energy sector, liquid fuels such as liquid hydrogen or liquid natural gas may experience vibrations in tanks and pipelines. Damping systems help ensure a stable supply of these fuels. Maritime and Shipbuilding Sector: In large maritime vessels and drilling platforms, the oscillations of seawater can affect stability and safety.

Damping systems can be used to reduce the impact of these vibrations. However, our topic is "The system of optimal damping of fire extinguishing liquid," which can be applied in the fire safety field. We will consider an example of optimal damping of fire extinguishing liquid in a firefighter aircraft's tank One of the effective ways to extinguish fires is the use of aviation. However, in the fire zone when dropping water, the aircraft must fly at low altitude, while testing significant impacts of air turbulence. which leads to fluctuations in their water. This creates additional difficulties when operating an aircraft.

As has been repeatedly emphasized, the problem of ensuring the dynamic stability of objects of such LA with liquid, taking into account the elasticity of their body and fluid mobility in tanks, is one of the main ones in the design of control systems for these objects. Naturally, various methods of its solution are given great attention in literature.

It seems expedient to perform studies related to the consideration of the mutual influence of aircraft dynamics as a solid mechanical system, together with dynamic modes of mobile capacity with fire fluid.

CHAPTER 1

UTILIZING AIRCRAFT FOR BATTLING FOREST FIRES

1.1 Utilizing Aircraft for Battling Forest Fires

Annually, forest fires, stemming from various causes, devastate millions of cubic meters of woodland, leading to substantial harm to states and communities. The spread of these fires can extend for hundreds of kilometers, contingent on factors such as wind speed, soil dryness, and other elements. To combat these fires, it is imperative to mobilize the best personnel and equipment. Various methods, ranging from digging firebreaks to controlled explosions, are employed, but the most promising approach for extinguishing forest fires involves the use of aviation. This approach significantly reduces response time and saves resources when tackling forest fire incidents.

An-32P in case of fire extinguishing is presented in Fig. 1.1.

Fig. 1.1 An-32P in case of fire extinguishing.

The primary configuration of the AN-32P firefighting aircraft is designed for extinguishing forest fires using fire retardant liquids. Its capabilities encompass:

1. Stopping and containing medium to large forest fires by creating a fire retardant barrier strip at the fire's edge;
2. Eliminating emerging small forest fires;
3. Transporting firefighting crews and equipment to disaster areas and returning them to base by landing on pre-selected water areas or airstrips.

The AN-32P can be swiftly and easily adapted to perform various tasks with minimal labor costs while retaining its firefighting capabilities. Additionally, it has been modified for purposes such as transport, passenger transport, search and rescue, and cleaning:

1. Transport;
2. Passenger ;
3. Search and rescue;
4. Cleaning.

Design features

The powerplant of the basic version includes two two-circuit turbojet engines, D-436TP, located above the wing root to protect them during takeoff and landing.

The modern integrated ARIA-200M electronic equipment ensures reliable piloting of the AN-32P in any global location and under various weather conditions.

The open architecture of the ARIA-200M system allows for configuration changes to meet customer requirements. The aircraft is crewed by two pilots.

The design of the AN-32P firefighting aircraft took into account the design experience and testing results from leading countries worldwide.

Features of operation. The AN-32P, also known as "Cline" according to NATO codification, is a versatile Ukrainian military aircraft designed for operating in extreme climatic conditions, including high temperatures (up to 50°C) and on large airfields (up to 4500 m). Its primary use is the transportation of cargo on medium and short routes, but it is also suitable for personnel transport, airdropping, and medical evacuation.

Characteristics of the aircraft.

Main features

Crew: 3-4 people

Passenger capacity: 30 parachute firefighters

Carrying capacity: 6700 kg

Length:

Elevation: 8.75 m

Wingspan: 29.20 m (79 mph)

Wing area: 74.98 m^2

Wing in plan: trapezoidal

Take-off weight: 27,000 kg (11,000 kg)

Fuel mass in internal tanks: 10080 l

Auxiliary power plant: 1 × gas turbine TG-16M

Flight characteristics

Maximum allowable speed: 530 km/h (330 mph)

Cruise speed: 460 km/h (220 km/h when extinguishing a fire)

Combat radius: 330 km

Range: 850 km (550 mi)

Distill range: 2000 km

Practical flight height: 9400 m

Acceleration length: 1800 m.

The general view of the AN-32P is presented in Fig. 1.2.

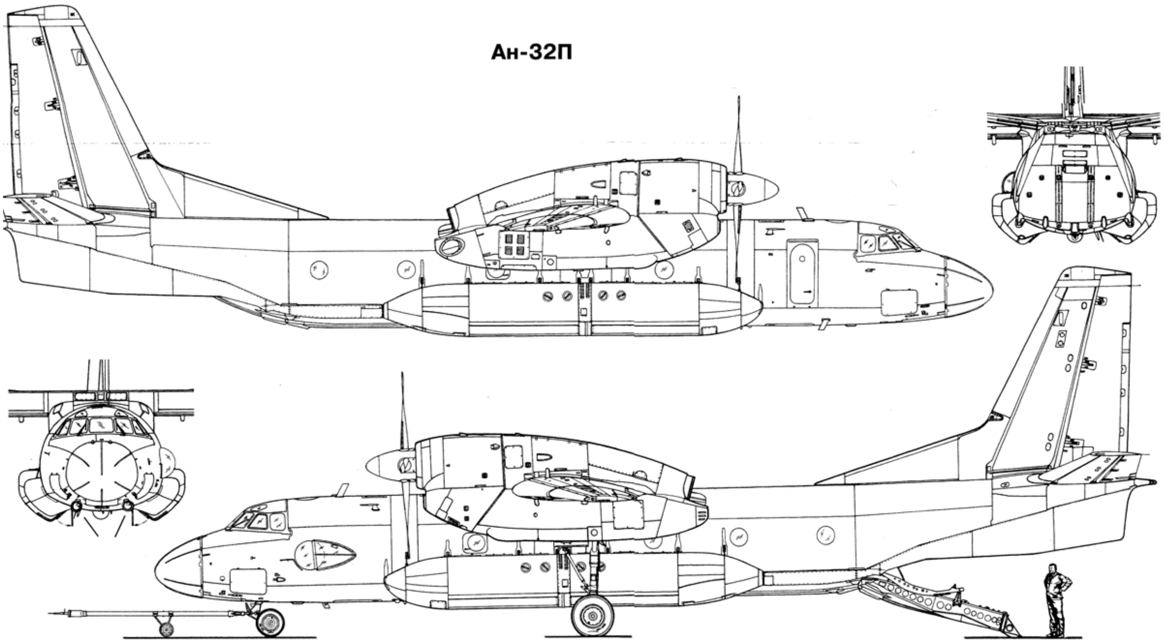


Fig. 1.2 AN-32P general view

The fire plane is equipped with four main tanks and two additional tanks, as depicted in Figure 1.3. The discharge of fire retardant liquid can be carried out in stages, either as a full "volley" or sequentially, depending on the task.

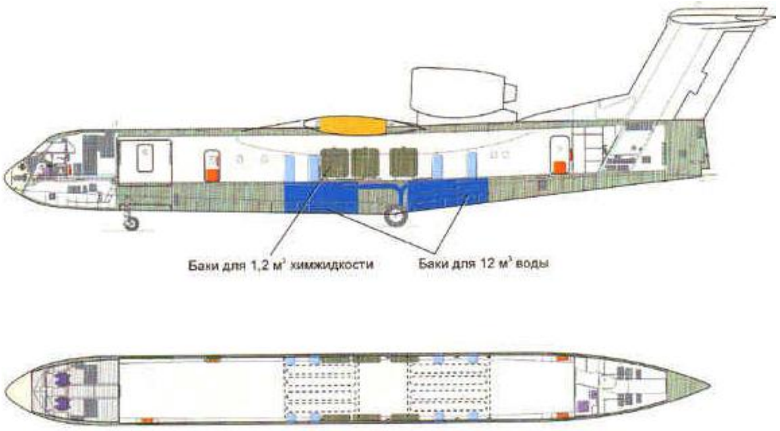


Fig. 1.3 Location of tanks

Due to its high flight speed, the AN-32P exhibits excellent performance in terms of the number of water discharges per hour, particularly when covering a distance of 100 km between the airfield and the fire zone. However, difficulties arise in managing the aircraft when delivering liquid to the fire zone, primarily because the fire plane's tanks are designed like bomb hatches. This design can lead to incomplete filling of the tanks during the refueling process, resulting in fluid sloshing. To mitigate this issue, the introduction of radial partitions to dampen fluid fluctuations in the AN-32P firefighter aircraft's tanks is necessary.

CHAPTER 2

APPROACHES TO MITIGATING OSCILLATION PHENOMENA

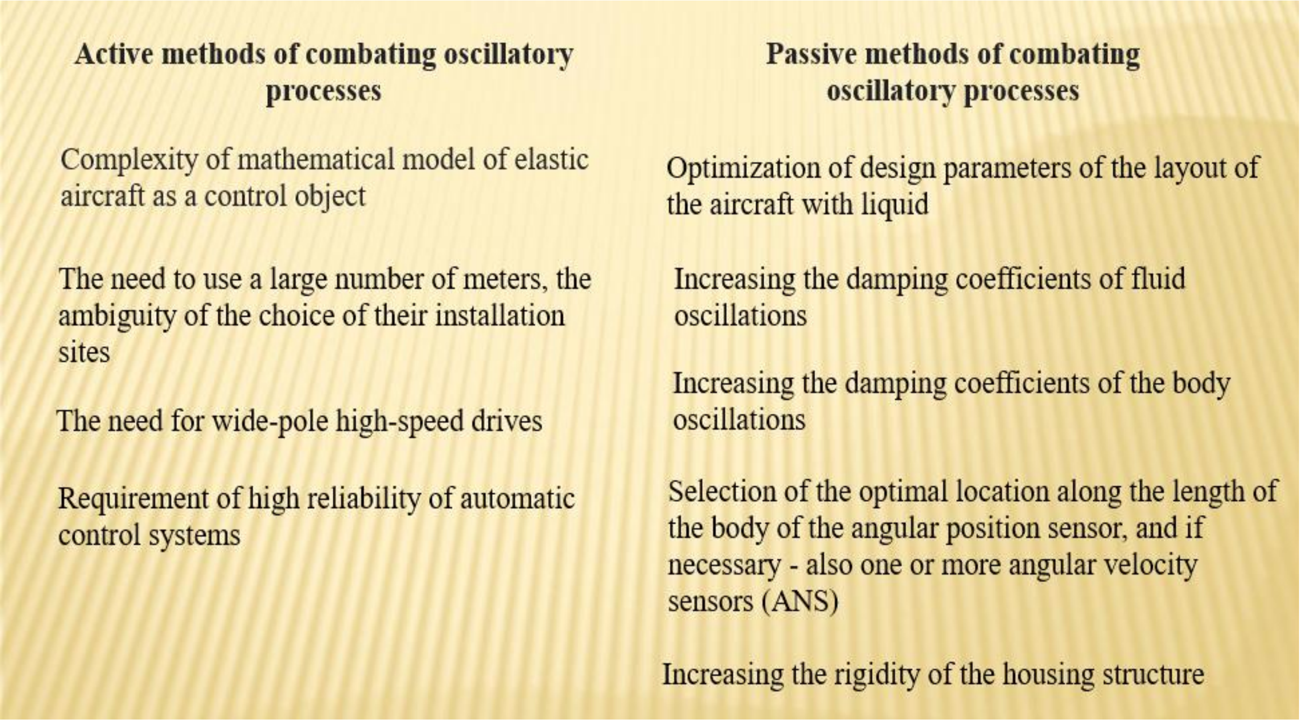
2.1 Approaches to Mitigating Oscillation Phenomena

There are two primary approaches to combat oscillation processes within the tanks of firefighting aircraft: active methods involving control system development and passive methods involving the installation of additional partitions within liquid containers. The methods used to dampen fluid oscillations in the aircraft can be categorized as follows, as shown in Figure 2.1.

These approaches can be categorized into two distinct directions:

1) active suppression of fluid vibrations in tanks and elastic vibrations of the body due to the stabilization machine using the appropriate sensors;

2) passive, related to the design of the object.



Active methods of combating oscillatory processes	Passive methods of combating oscillatory processes
Complexity of mathematical model of elastic aircraft as a control object	Optimization of design parameters of the layout of the aircraft with liquid
The need to use a large number of meters, the ambiguity of the choice of their installation sites	Increasing the damping coefficients of fluid oscillations
The need for wide-pole high-speed drives	Increasing the damping coefficients of the body oscillations
Requirement of high reliability of automatic control systems	Selection of the optimal location along the length of the body of the angular position sensor, and if necessary - also one or more angular velocity sensors (ANS)
	Increasing the rigidity of the housing structure

Fig. 2.1 Methods of combating oscular processes

2.2 Active methods of combating oscular processes

Active methods of combating oscular processes involve the synthesis of an active control system (in this case, stabilization systems), as well as the choice of control bodies and information sensors. One of the main tasks of active control systems consists in ensuring stability and reducing the loads acting on the aircraft.

The analysis showed that the difficulty of creating active ACS is explained by:

- complexity of the mathematical model of the elastic aircraft as an object of control;
- the need to use a large number of meters, the ambiguity of the choice of their installation sites;
- the need to use wide-field high-speed drives;
- requirement of high reliability of automatic control systems (ACS).

Mathematical models describing the behavior of an elastic aircraft are multidimensional multi-bond systems.

Frequencies of individual degrees of will, the shape of the tones of elastic vibrations, the effectiveness of steering wires vary significantly by flight modes, which leads to the need to design adaptive automatic control systems.

Methods of synthesis of active ACS, based on classical methods of correction of systems require greater labor costs and are characterized by the following disadvantages:

1. Low level of optimization;
2. A small degree of unification;
3. Difficulties in ensuring the adaptive properties of a closed system.

Recently, the design of active ACS is carried out by techniques that will use modern methods of the theory of optimal control.

To achieve adaptive properties, it is necessary to solve the problem of current identification of parameters of the mathematical model of the control object.

2.3 Passive Methods for Combating Oscillation Phenomena

Passive methods aim to ensure dynamic stability within a closed system over a range of natural frequencies of elastic vibrations of the aircraft's structure and liquid oscillations. These methods can be categorized as follows:

1. Optimization of the structural design parameters of the aircraft's layout with liquid containers
2. Increasing the damping coefficients of liquid oscillations.
3. Enhancing the damping coefficients of structural vibrations.
4. Selecting optimal positions for angular position sensors along the length of the aircraft's body, and, if necessary, additional angular velocity sensors.
5. Increasing the structural stiffness of the aircraft's body.

The mathematical problem related to fluid dynamics in a movable solid cavity is complex and still unresolved. Assumptions are often made to simplify the problem, such as assuming the liquid is ideal, incompressible, and homogeneous, and that external forces acting on the liquid are potential. This simplification allows for a more manageable analysis, although it may not fully represent real-world complexities. Various methods, such as finite differences, finite element methods, and boundary element methods, have been used to address these challenges. These methods offer different advantages and disadvantages, including issues related to convergence, choice of difference schemes, and computational complexity. Variational methods, such as the Ritz method, have also been applied to solve problems related to liquid-filled cavities.

The choice of coordinate functions and their properties play a crucial role in the effectiveness of these methods. The Laplace equation, attenuation properties, and other characteristics are considered in selecting suitable coordinate function systems. Additionally, direct methods, like those developed by O.O. Lymarchenko, offer advantages in terms of dimension reduction but come with challenges related to integration and solving linear algebra problems for asymmetric matrices. In summary, the study of dynamic interactions between structures with liquid-filled cavities is essential in various fields, including aviation, rocketry, and space technology. Researchers have explored various methods, both active and passive, to mitigate oscillation phenomena and ensure the stability and safety of these systems.

These approaches range from mathematical modeling and analytical solutions to numerical simulations and experimental studies. Despite the complexities involved, continued research aims to enhance our understanding and control of these systems.

2.4 Overview of Research on the Formulation, Analysis, and Methods for Solving Problems in the Dynamics of Elastic Mechanical Systems Containing Liquid-Filled Cavities

The necessity for a comprehensive examination of the dynamic interaction between structures and the liquid partially occupying their cavities has become increasingly significant due to the rapid advancements in aviation, rocketry, and space technology. The formulation of equations describing the motion of a body with a cavity partially filled with fluid has been the focus of research by various authors, including N.N. Moiseev, G.S. Narimanov, D.E. Okhotsymsky, V.I. Rabinovich, G.N. Mykyshev, S.F. Feshchenko, and others.

In order to compute fluid oscillation parameters for complexly shaped cavities, several approaches for approximating hydroelasticity problems have gained widespread attention:

1. Methods based on discretizing system parameters;
2. Variational methods that employ specific coordinate function systems;
3. The direct LymarchenkoO.S. method;
4. Methods relying on information from systems of ordinary differential equations.

Unlike the Fourier method, which provides analytical expressions for dynamic characteristics of completely solid cavities partially filled with liquid, these methods, in certain cases, allow for the calculation of coupled oscillation parameters of elastic structures with liquid. The first approach encompasses methods such as the finite differences method (MKR), finite element method (MKE), and boundary element method (MGE).

These methods offer the advantage of approximate solutions to the dynamics of liquid-containing structures with complex cavities, but they require substantial computational memory and processing time, depending on the cavity's shape.

Factors like grid convergence, choice of difference schemes, and selection of final or boundary elements become pertinent when using these methods. Notably, MKE and MGE are more frequently discussed in international literature, whereas MKR is more common in domestic research.

However, MKR's effectiveness is limited to cavities aligning with the coordinate planes of any curvilinear orthogonal coordinate system. MKE has gained widespread use in analyzing complex structures, particularly as a variational method and often employed as the Ritz method. Unlike the variation-difference method, MKE emphasizes the role of element shape functions, which are essential for interpolation properties. In one of the articles, MKE is discussed concerning the coupled oscillations of viscoelastic shells with liquid, varying the wavenumber. The shell is represented schematically using ring elements. To approximate the fluid particle shear potential, isoparametric triangular elements with six nodes are employed.

The solvable equations are derived using the Hamilton's Principle. The computational efficiency of the developed program is evaluated, revealing that the number of degrees of freedom in the MKE model can reach 500-600 without the need for external storage devices, with a computation time of 2.5-3 minutes per natural frequency.

The article also presents results for calculating the natural frequencies and modes of vibration of various shells with liquid, depending on the filling level of the shell.

When addressing dynamic problems in structures with liquid-filled cavities, it's crucial to have a hydrodynamic solution only on the liquid's boundary. MGE, which has seen considerable development in recent decades, offers advantages, including equations that involve the function and its derivative solely at the boundary. The method can be categorized into direct and indirect formulations.

In the indirect formulation, the function within the region is represented as the potential of distributed sources along the boundary with an unknown distribution density. In the direct formulation, equations are constructed using a weighted residual method, with the fundamental solution of the Laplace equation serving as the consistent function. While MGE reduces the problem's dimensionality per unit area, it entails challenges such as integrating expressions with singularities and solving linear algebraic systems for equations with asymmetric matrices.

In addition to techniques relying on discrete parameter representations, the issue at hand is also explored through variational approaches, including the Ritz method and its assorted adaptations

One of the initial works that extensively addressed the alternative approach is the book by N.N. Moiseev and A.A. Petrov, referenced as /3/. In this book, solutions to corresponding problems using the Fourier method are presented for various geometries such as a rectangular channel, a parallelepiped, and a circular cylinder, among others.

The book also demonstrates the equivalence of the Hamiltonian principle to the differential formulation of the problem and explores the capabilities of the Ritz method in addressing regional problems that arise. Additionally, the variation method is employed to tackle problems related to different cavity shapes, including inclined circular cylinders, cones, spheres, horizontal coaxial cylinders, horizontal cylinders, cylinders with spherical bottoms and covers, and tori. It is worth noting that the variation method yielded satisfactory results across all the cases examined S.F. Feshchenko and co-authors further extended the modifications of the Ritz method to address viscometric cavities and cavities with solid radial partitions in their work. Additionally, they employed various mathematical techniques, including the method of separating variables, solution matching for different regions, and integral estimates.

In the Ritz method, particular emphasis was placed on harmonic functions constructed using Legendre's associated functions. Different sets of fundamental functions were chosen based on the potential existence of solution features along.

In the study, the work addresses strategies for enhancing the effectiveness of the Ritz method and its diverse adaptations when applied to intricate cavity geometries. This discussion specifically revolves around the essential characteristics of coordinate functions.

Let's take a closer look at the features you are employing. It's important to highlight that the rate of convergence from an approximate solution to an exact one is greatly influenced by the careful selection of the initial function, the choice of functions that inherently possess known properties of the solution, and the selection of a suitable coordinate system when spherical functions are utilized. This becomes particularly evident when assessing the calculation results for various dynamic parameters in different cavity geometries such as cylinders, cones, and spheres.

Evidently, the most significant progress in applying the Ritz method to determine hydrodynamic coefficients can be attributed to the research conducted by I.A. Lukovskyi and his collaborators.

Continuing with the discussion, the book delves into the potential of the variational method. It's worth noting that this method leads to approximate solutions characterized by a general weak convergence. Nevertheless, these approximate solutions, obtained through the variational method, prove to be quite suitable for practical applications, especially when dealing with dynamic properties of integral-type liquids, such as oscillation frequencies, attached masses, and moment of inertia. However, the selection of a coordinate function system remains a complex challenge, intertwined with issues of Ritz algorithm stability, convergence, and dimension reduction of the algebraic equation system.

The foremost requirements for the coordinate function system involve completeness and linear independence, prerequisites for the successful application of the Ritz method to address variational problems. Nonetheless, when aiming for an approximate solution with optimal accuracy, computational efficiency, or as a foundational solution for nonlinear problems, additional properties of the coordinate function system can be demanded to enhance the efficacy of the Ritz method. These properties might include the satisfaction of the Laplace equation, properties promoting solution attenuation in one of the variables, or the ability to approximate the exact solution near angular points or domain edges.

Consequently, the effectiveness of the Ritz method significantly improves, leading to approximate solutions that not only converge on average but also in a uniform metric. The work also analyzes the analytical properties of eigenfunctions at critical points and provides asymptotic decompositions of these functions near angular points in specific scenarios.

When exploring methods to construct coordinate function systems, particular attention is given to spherical functions and harmonic polynomials. Numerical evaluations using the Ritz method are conducted for various cavity shapes, including the inclined cylinder, inclined cone, and horizontal forming cylinder. These results are compared with existing solutions for these cavity geometries. In reference [2], the work addresses the pressing issue of calculating the dynamic characteristics of cavities equipped with rib-like dampers that affect fluid oscillations. In this context, they achieved an enhancement in the coordinate function system by incorporating properties of the sought solutions near specific points along the boundary of the liquid-filled region. In the linear framework, a mathematical model is developed for the complex motion of a solid body containing viscometric cavities filled with liquid and featuring elastic ring-like edges. The primary regional problems are defined, which must be solved to determine the parameters.

An approximate method for solving these problems is proposed, involving the subdivision of the liquid-filled area into simpler sub-regions and the formulation of certain boundary problems within them. This approach allows for a seamless integration of solutions, taking into account characteristics near the corner points of the boundary. For cases involving cavities in the shape of a circular cylinder with a ring-like partition, the construction of solutions for auxiliary problems relies on the use of corresponding Green's functions. Meanwhile, for a broader category of rotating cavities with ring-like edges, the solution of auxiliary problems is accomplished through a variational method, preceded by the adjustment of boundary conditions. N.S. Syvova and V.N. Gurkyn's research provides computed results for hydrodynamic coefficients in the equations describing the complex motion of a solid body interacting with a liquid, considering various cavity configurations.

Currently, a promising approach is emerging, founded on direct methods pioneered by O.O. Limarchenko. These methods have a unique characteristic in that they allow solutions to corresponding linear problems to be selected as the coordinate function system. In reference [3], the author conducted a study on transitional modes of a spatial motor tank containing liquid. Specifically, they tackled several problems related to the simultaneous motion of the tank and the liquid in response to various types of pulse loads. The mathematical model considered as many as 14 modes of fluid oscillations in these analyses.

When addressing various engineering problems related to vibrations in thin-walled structures, the shapes of transverse oscillations characterized by a specific number of waves in the circumferential direction ($t = 1$) play a pivotal role. This significance is particularly evident in aerospace and missile structures, where these oscillation patterns are crucial due to their involvement in feedback systems through sensors and actuation components of corrective devices.

Due to the heightened interest of engineers in these specific oscillation patterns, a third approach to solving boundary problems for liquid shell systems gained popularity. This approach is based on the Bubnov-Galerkin method and its variations. At certain values of T, it is convenient to approximate the design of highly elongated structures as one-dimensional elastic systems with attached oscillators (masses connected by elastic bonds).

This approximation effectively reproduces the primary modes of vibration exhibited by thin-walled structures with liquid-containing compartments in the relevant frequency range, as discussed in references [1,2,3]. One typical example of a highly elongated structure is the T-shaped aircraft tail, designed to carry firefighting liquid. The authors of this study investigated the problem of oscillations in cylindrical compartments with solid bottoms, partially filled with liquid, featuring a single wave in the circumferential direction.

Notably, the initial solutions were independently obtained by both Miles [3] and B.M. Rabinovich [1]. In Miles' work, the potential velocities were determined using a 'hard cover' approach, which resulted in somewhat complex formulas.

Conversely, in reference [1], the solution was presented employing the 'floating cover' scheme, yielding more intuitive outcomes and facilitating a natural transition to both solid compartments with free deformable liquid surfaces and elastic compartments with quasi-rigid liquids.

Extending the findings from reference [1] to the case of a conical shell, deformed according to the thin-walled rod scheme outlined in L.V. Dokuchaev's work [4], is a noteworthy generalization. It's worth mentioning the work by Lyndholm Chu, Kahn, and Abramson [4], which offers an extensive numerical analysis of the impact of fluid mobility on the shapes and frequencies of transverse oscillations in cylindrical shells, along with presenting some experimental results.

In Bower's study, the solution to boundary problems for cylindrical shells was obtained using Miles' approach, wherein the shells were divided by solid radial partitions into independent compartments. Meanwhile, for coaxial shells with similar partitions, the solution to the same problem, as described in references [3,4], was modified using the Bubnov-Galerkin method by L.I. Balabuh, A.I. Ganychev, and A.G. Molchanov [4]. The specific modification proposed by V.P. Shmakov allowed for the relaxation of constraints regarding the coordinate functions used for solving the boundary conditions of the problem.

The generalization of results in this direction was undertaken by Mykyshev and G.N. Rabinovich [1]. The book presents a conclusion and analysis of the equations governing the motion of thin-walled structures containing liquid, employing the Bubnov-Galerkin method.

There are two sets of functions serving as fundamental components:

1) The eigenfunctions of the partial system pertain to the liquid oscillations within a rigidly fixed tank;

2) The eigenfunctions are associated with the problem of damping vibrations of the shell filled with liquid when there are no waves present on the free surface of the liquid.

It is worth highlighting that the selection of these fundamental functions results in a system of equations comprising two subsystems, with relatively weak inertial connections between them. In simpler terms, the generalized coordinates associated with the chosen fundamental functions closely approximate the primary ones, leading to favorable conditioning of the system matrix.

The calculation of the coefficients for the governing equations is carried out analytically for a structural configuration, which is represented as an elastic rod with a compartment partially filled with liquid. This compartment is formed by a cylindrical casing with gently curved spherical shells as bottoms. Consequently, to transition from the original structure to an equivalent rod in the context of longitudinal oscillations, information regarding the frequency and mass of the oscillator corresponding to the primary mode of waveless viscometric vibrations in each bearing compartment (which are linked to deformation or its walls) is necessary.

In the case of transverse and torsional vibrations, information is needed about the frequencies of natural vibrations of the compartment on elastic connections (suspension compartment), as well as the frequencies and added masses of liquid corresponding to the first mode of wave movements that occur when the compartment rotates along both transverse and longitudinal axes. As a result, the task of analyzing the dynamic characteristics of elastic thin-walled structures with compartments partially filled with liquid can be reduced to the examination of several systems of ordinary differential equations.

The coefficients of these equations are determined through numerical integration techniques, provided that solutions to the fundamental boundary problems in fluid dynamics for mobile cavities and information about the frequencies and modes of natural oscillations of equivalent elastic rods are available.

The variational Ritz method is regarded as the most effective approach for solving the boundary problem in fluid dynamics. To obtain the shapes and frequencies of elastic oscillations within an equivalent beam-like structure, practical application often involves one of the established methods:
1. Method of sequential approximations /1/;

2. Sampling method /2/;

3. The method referred to as the 'initial parameters method,' also known as the 'run method' [3], can be described by three distinct approaches. The first approach is characterized by its high computational speed, but it does not independently allow for the determination of higher-order oscillation modes. This limitation arises because it necessitates orthogonalizing each nth mode against all the n-1 preceding modes.

The second approach enables the simultaneous determination of all frequencies and eigenmodes of the chosen analog of the output system, which has a finite number of degrees of freedom. However, this method exhibits limited flexibility, as any alterations to the boundary conditions require updating all the influence coefficients. The third approach combines the strengths of the first and second methods while avoiding their inherent drawbacks. It permits the independent calculation of each frequency and eigenmode of the oscillations and offers ease in modifying boundary conditions and characteristics of the attached oscillators, with minimal constraints on their number.

The analysis of the aforementioned sources provides insight into a portion of the research on the discussed problem. Nonetheless, it is apparent that calculating the dynamic characteristics of elastic mechanical systems containing liquid remains a challenging task, even in a linear context, without considering factors like viscosity, compression, and the compressibility of the liquid.

CHAPTER 3

HYDRODYNAMIC FORCES EXPERIENCED WITHIN THE RESERVOIR OF A FIREFIGHTER AIRCRAFT

3.1 Hydrodynamic forces experienced within the reservoir of a firefighter aircraft

Until now, we have primarily focused on ideal (conservative) systems, where fluctuations can persist indefinitely. However, real systems exhibit some level of damping. When developing algorithms for controlling firefighting aircraft during fire suppression operations, it becomes necessary to create a mathematical model that considers fluctuations in both the aircraft's design and the partially filled tanks of fire-extinguishing liquid as the aircraft moves into the fire zone.

To evaluate the impact of symmetric tone on the determination of damping coefficients, experimental studies can be conducted. In these experiments, a cylindrical tank with six evenly spaced radial ribs on its wall was employed. The tank had a diameter of 666 mm, and the ribs were 0.283 times the radius in height. The tank was filled with water up to a level of 525 mm.

The damping coefficients were determined using two standard methods: the free oscillation method and the forced oscillation method. Additionally, we utilized a test stand to determine the natural frequencies and modes of fluid oscillations.

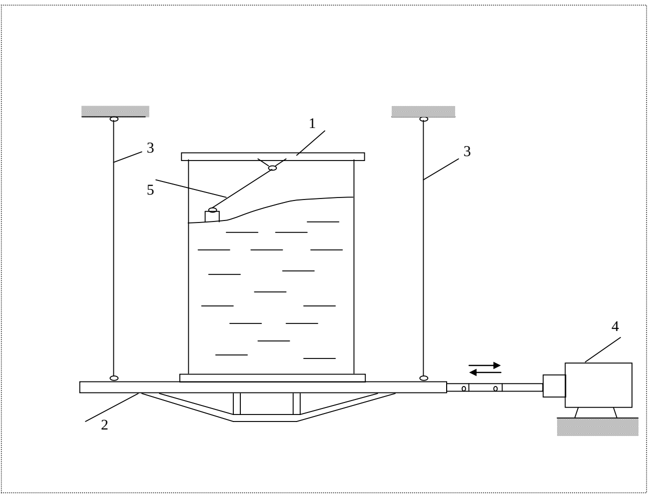


Fig. 3.1 Test scheme to determine the own frequencies and forms of oscillations of the free surface of the liquid

One possible experimental setup for studying translational movements is illustrated in Figure 1. In this setup, a test tank (designated as 1) is placed on a platform (designated as 2), which is suspended by four parallel cables (designated as 3) and subjected to harmonic motion controlled by a specialized oscillator (designated as 4). Typically, an eccentric drive or hydraulic drive is used as the source of these oscillations.

An essential criterion for these testing facilities is that they must possess adequate rigidity in all their moving components. In other words, the natural frequencies of the platform-tank system, considering the elasticity of the moving components, should significantly surpass the range of natural frequencies associated with fluid oscillations. Failing to adhere to this requirement can result in substantial inaccuracies when determining the natural frequencies of liquid oscillations.

3.2 Hydrodynamic forces acting in the compartment without any structural elements on its walls

When dealing with smooth-walled compartments, the influence of liquid viscosity primarily results in the introduction of dissipative forces into the equations governing fluid motion. Simultaneously, nearly all hydrodynamic coefficients within the equations related to an ideal fluid remain largely unaffected.

These forces are typically derived based on the boundary layer hypothesis, which employs expressions for hydrodynamic forces due to liquid viscosity originally developed for a flat plate undergoing harmonic vibrations within the viscous liquid in its plane. To illustrate, let's consider a two-dimensional scenario involving the harmonic oscillations of a flat plate immersed in an unbounded viscous liquid on one side.

We establish a coordinate system denoted as Oxyz, where the Oy axis is oriented perpendicular to the plate and extends into the liquid, while the Ox and Oz axes lie within the plate's plane. The oscillations take place along the Ox axis, following a specific pattern.

$$u_y = u_z = 0; \quad u_x = u = u_0 e^{i\omega t}. \tag{3.1}$$

The edge task for the Nave - Stokes equations in this case looks like

$$\frac{\partial \nu}{\partial t} + (\nu, \nabla) - v\Delta\nu + \frac{1}{\rho}\nabla p = 0. \tag{3.2}$$

$$(\nabla, \nu) = 0;$$

$$\nu\big|_{y=0} = \dot{u}; \tag{3.3}$$

$$\nu\big|_{y\to 0} \to 0.$$

Obviously, $\upsilon_z \equiv 0$, all variables are functions *y* and *t*.

$$\frac{\partial \upsilon_y}{\partial y} = 0 \to \upsilon_y = const;$$

$$(v, \nabla)v = \upsilon_y \frac{\partial v}{\partial y} = 0.$$

Navier-Stokes equation (3.2) in a given case acquires the same form as after linearization in a common spatial task and takes the form of:

$$\frac{\partial \nu}{\partial t} = -\frac{1}{\rho}\nabla p + v\Delta\nu. \tag{3.4}$$

Hence, taking into account previous equalities, we have

$$\frac{\partial p}{\partial y} = 0 \to p = const;$$

As a result of equation (3.4) for *x* - the speed component to go into the equation type of one-dimensional equation of thermal conductivity $\vartheta_x = \vartheta$

$$\frac{\partial v}{\partial t} = \nu \frac{\partial^2 \upsilon}{\partial y^2} \tag{3.5}$$

with boundary conditions

$$\upsilon\big|_{y=0} = \dot{u}; \quad \upsilon\big|_{y\to \inf ty} = 0. \tag{3.6}$$

Periodic solution of this problem, satisfying conditions and conditions ($\upsilon(0,t) = \upsilon_0 e^{i\omega t}$ 3.6), has the form of a transverse wave, exponentially fading into the middle

$$\upsilon = \upsilon_0 \exp\left[-\sqrt{\frac{\omega}{2v}}\, y\right] \exp i\left(\sqrt{\frac{\omega}{2v}}\, y + \omega t\right) = \dot{u} \exp\left(\sqrt{\frac{\omega}{2v}}(1-i)y\right). \tag{3.7}$$

The "penetration depth" of this wave, that is, the distance from the plate on which the amplitude falls *e* time,

$$\delta=\sqrt{\frac{2\upsilon}{\omega}}\,. \qquad (3.8)$$

The friction force acting per unit area of the plate is determined by the formula τ

$$\tau=\nu\rho\left.\frac{\partial\upsilon_x}{\partial y}\right|_{y=0}=\rho\sqrt{\frac{\omega\nu}{2}}(i-1)\dot{u}. \qquad (3.9)$$

By entering some characteristic size *l*, you can add a view to this expression

$$\tau=-\frac{\rho\omega l}{\sqrt{2R}}\dot{u}+\frac{\rho l}{\sqrt{2R}}\ddot{u};\quad R=\frac{\omega l^2}{\nu} \qquad (3.10)$$

The initial component represents the dissipative component of the force acting on the plate, while the second one is related to inertia. In cases with higher Reynolds numbers, the second component can often be neglected, which means,

$$\tau=-\frac{\rho\omega l}{\sqrt{2R}}\dot{u}$$

Note that the proportionality coefficient is a function of only one dimensionless parameter, but does not depend on the relative amplitude of oscillations $\dot{u}$ $R=\frac{\omega l^2}{\nu}$.

This rationalizes the adoption of the Reynolds number as this parameter. In the general scenario of arbitrary motion of the plate within its plane, as described by the function u = u(t), the expression for the force acting on a unit area of the plate takes the following form

$$\tau=\rho\sqrt{\frac{\nu}{\pi}}\int_{-\infty}^{t}\frac{d^2u(\xi)}{d\xi^2}\frac{d\xi}{\sqrt{t-\xi}}\,. \qquad (3.11)$$

3.3 Hydrodynamic forces when structural elements and compartments are present

To consider the hydrodynamic effects introduced by different structural elements within the compartment, such as radial and ring edges, adjustments are made to the initial relationships governing hydrodynamic forces. Assuming that the overall hydrodynamic force exerted on the body in an unsteady flow can be expressed as

$$F = -m\frac{d\upsilon}{dt} - \frac{1}{2}c_b\rho S|\upsilon_0|\upsilon, \qquad (3.12)$$

where$m$ - attached mass of liquid, c_b - resistance coefficient, υ - flow rate, S - theareaofthebody." Instead of the value *of* m , a dimensionless value is often introduced, the so-called coefficient of the attached mass of the liquid

$$c_m = \frac{4m}{\pi\rho bS}. \qquad (3.13)$$

here$b$ - characteristic linear size (for example, rib height).

Let $\upsilon=\upsilon_0 cos\theta=\upsilon_0 cos\omega t$. Let's give you the expressions (3.12) to a dimensionless form:

$$\frac{F}{\rho\upsilon_0^2 S} = \frac{\pi}{4}c_m\sin\theta - \frac{1}{2}|\cos\theta|\cos\theta. \qquad (3.14)$$

In the case of boundless fluid, *the* coefficients c_m and c_b will depend on three dimensionless parameters - the Strhal number, the Reynolds number $\theta = \omega t,\ S = \frac{2\pi\upsilon_0}{b\omega}$ $R = \frac{\upsilon_0 b}{\nu}$, ν is the kinematic viscosity .So, these coefficients can be considered as functions only θ and S. Decompose the hydrodynamic force in the Fourier series.

$$\frac{F}{\rho v_0^2 S} = A_1\sin\theta + A_2\sin3\theta + A_5\sin5\theta + ... + B_1\cos\theta + B_3\cos3\theta + B_5\cos5\theta + ... \qquad (3.15)$$

There are no paired harmonies in this decomposition, because due to the symmetry of the flow, the condition is met

$$F(\theta) = -F(\theta-\pi).$$

$$A_n = \frac{1}{\pi}\int_0^{2\pi}\frac{F\sin n\theta}{\rho\upsilon_0^2 S}d\theta; \qquad (3.16)$$

$$B_n = \frac{1}{\pi}\int_0^{2\pi}\frac{F\sin n\theta}{\rho\upsilon_0^2 S}d\theta. \qquad (3.17)$$

Let's turn the series (3.15) to a species convenient for comparison with (3.14). Let's use decomposition

$$|\cos\theta|\cos\theta = a_0 + a_1\cos\theta + a_2\cos 2\theta + ... \qquad (3.18)$$

$$a_n = \begin{cases} (-1)^{(n+1)/2}\dfrac{8}{n(n^2-4)\pi} & \text{при парних n,} \\ 0 & \text{при непарних n.} \end{cases}$$

Using the schedule (3.18) and entering the designation

$$B_1' = \frac{B_1}{a_1};\;\; B_3' = B_3 - \frac{a_3}{a_1}B_1, ...$$

Obsessively

$$\frac{F}{\rho\upsilon_0^2 S} = A_1 + B_1'\cos\theta|\cos\theta| + \Delta R, \qquad (3.19)$$

where

$$\Delta R = A_3\sin 3\theta + A_5\sin 5\theta + ... + B_3'\cos 3\theta + B_5'\cos 5\theta + ...$$

By comparison (3.13) and (3.14) we find

$$\frac{\pi}{4}c_m(\theta)\frac{b\omega}{\upsilon_0} = A_1 + a_3\frac{\sin 3\theta}{\sin\theta} + ... \qquad (3.20)$$

or

$$c_m(\theta) = \frac{\pi}{4}\frac{b\omega}{\upsilon_0}[A_1 + a_3 + ... + 2(A_3 + A_5 + ...)\cos 2\theta + 2(A_5 + ...)\cos 4\theta + ...] \qquad (3.21)$$

$$c_b(\theta) = -2B_1' + \frac{2}{|\cos\theta|}[B_3' - B_5' + ... - 2(B_3' - B_5' + ...)\cos 2\theta - 2(B_5' + ...)\cos 4\theta - ....]. \qquad (3.22)$$

If in decomposition (3.19) can be despised by higher harmonics $(A_3 = A_5 = ... = B_3 = B_5 = ... = 0)$, then the coefficients of the attached mass and resistance will be constant throughout the period of oscillations and can be determined by the formulas

$$c_m = \frac{4}{\pi}\frac{\upsilon_0}{b\omega}A_1 = \frac{4}{\pi}\frac{\upsilon_0}{b\omega}\int_0^{2\pi}\frac{F\sin n\theta}{\rho\upsilon_0^2 S}d\theta; \qquad (3.23)$$

$$c_b = -2B_1' = -\frac{3}{4}\int_0^{2\pi}\frac{F\cos\theta}{\rho\upsilon_0^2 S}d\theta; \qquad (3.24)$$

If higher harmonics cannot be despised, then c_m and $c_b$are conditioned by expressions (3.23), (3.24), can be interpreted as average weighted values

$$c_m = \frac{1}{\pi}\int_0^{2\pi} c_m(\theta)\sin^2\theta d\theta; \qquad (3.\ 25)$$

$$c_b = \frac{3}{4}\int_0^{2\pi} c_b(\theta)|\cos\theta|\cos^2\theta d\theta. \qquad (3.26)$$

Thus, the final expression for hydrodynamic force takes the form of

$$\frac{F}{\rho\upsilon_0^2 S} = \frac{\pi}{4}c_m\frac{b\omega}{\upsilon_0}\sin\theta - \frac{1}{2}c_b|\cos\theta|\cos\theta + \Delta R. \qquad (3.27)$$

The coefficients in this equation are solely contingent on the dimensionless parameter S. They can be readily calculated using formulas (3.23) and (3.24), provided that the primary harmonics of the hydrodynamic force decomposition or the forces themselves are known. The function can also be determined if needed, although in the majority of practical scenarios, it can be disregarded Nonlinear Member in (3.27), which corresponds to the resistance force F_c can be replaced by an equivalent linear

$$\frac{F_c'}{\rho\upsilon_0^2 S} = -\varepsilon_0 c_b\cos\theta, \quad \varepsilon_0 = \frac{4}{3\pi}.$$

Coefficient ξ_0 select from the condition of equality of dissipation of energy oscillations for the period for linear and nonlinear laws of resistance.

$$\frac{F}{\rho\upsilon_0^2 S} = \frac{\pi}{4}c_m\frac{b\omega}{\upsilon_0}\sin\theta - \frac{4}{3\pi}c_b\cos\theta. \qquad (3.28)$$

Both these equations (as well as equations (3.27)) can be applied to solve a range of different problems. As evident from expressions (3.23) and (3.24), to calculate the coefficients cm and cb, it is essential to have knowledge of the amplitude of flow velocity fluctuations (typically obtained through experimental measurements), as well as the coefficients A1, which can be readily determined by measuring the amplitude of motion $B_1' = 3\pi / 8 B_1 \upsilon_0 = \upsilon_0 \omega u_0$ and the frequency of ω. Coefficients A_1, B_1 are associated with the main components of the hydrodynamic force: the force of inertia F_u and the resistance force F_c:

$$A_1 = \frac{F_u^0}{\rho \upsilon_0^2 S}; \qquad B_1 = \frac{F_c^0}{\rho \upsilon_0^2 S}. \tag{3.29}$$

Index 0 in these expressions indicates that amplitude values of forces are taken F_u й F_c .

$$c_m = \frac{4}{\pi} \frac{\upsilon_0}{b \omega \upsilon_0} \frac{F_u^0}{\rho \upsilon_0^2 S}; \; c_p = \frac{3\pi}{4} \frac{F_u^0}{\rho \upsilon_0^2 S}. \tag{3.30}$$

3.4 Hydrodynamic force in the presence of radial ribs

When fluid oscillations occur within a compartment containing internal structural elements, additional hydrodynamic forces come into play. We present simplified calculation formulas for two primary types of structural elements: radial and ring ribs situated along the compartment's walls.

The expressions for hydrodynamic force exerted on a unit of edge length can be formulated as follows

$$f = -\rho b^2 \left(\frac{\pi}{4} c_m \ddot{u} + \frac{4 \omega u_0}{3 \pi b} c_b \dot{u}\right)., \tag{3.31}$$

whereb – rib height, c_m - bound mass coefficient, c_b - resistance coefficient. This expression, strictly speaking, is only true for harmonic oscillations ($u=u_0 sin\omega t$).

In small amplitudes of oscillations $(u_0<0.3b) c_m$ is weakly dependent on *parameters* S and practically coincides with the theoretical value $c_m=2$.

$$f_u = -\frac{\pi}{2} \rho b^2 \ddot{u}. \tag{3. 32 }$$

The analysis reveals that if the liquid oscillations within a cylindrical compartment with radial and ring ribs remain within a range of 0.1 times the radius, then in many instances, it is sufficient to consider only the inertial forces using formula (3.32). It's worth noting that when the ribs are of low height, the coefficient ct may deviate significantly from the constant value of ct = 2, rendering formula (3.32) inaccurate. Nevertheless, in cases with low rib height, changes in hydrodynamic coefficients attributed to the presence of ribs within the compartment.

The resistance coefficient, cb, included in the second component, exhibits a notable dependency on the parameter S. For radial ribs, the resistance coefficient for the vertical edge can be expressed using the following experimentally derived formula:

$$c_b = 19.1\left(\frac{2\pi u_0}{b}\right)^{-\frac{1}{2}}\left(1 + 0.4e^{\frac{0.138(x'-h)}{b}}\right), \tag{3.33}$$

where x' - distance from the cross section of the rib in question to the free surface of the liquid.

With this in mind, the hydrodynamic force acting per unit of edge length is determined by the formula

$$f_u = -\rho b^2\left[\frac{\pi}{2}\ddot{u} + 3{,}23\omega\sqrt{\frac{u}{b_0}}\left(1 + 0.4e^{\frac{0.138(x'/b)}{b}}\right)\dot{u}\right]. \qquad (3.\ 34)$$

When dealing with antisymmetric liquid fluctuations, the coefficient K should be chosen to achieve equality between the calculated and experimental values of the damping coefficients.

So, for a edge with a height of $b = 0.1r_0$, $K = 11.3$.

In both cases, the height of the ribs is not to blame for exceeding 0.2 radius.

CHAPTER 4

Damping of the Liquid System with Radial Partitions in the Tank of a Firefighter Aircraft

4.1 Damping of the Liquid System with Radial Partitions in the Tank of a Firefighter Aircraft

The experimental data provided for attached masses and resistance coefficients mentioned above can be employed to approximately determine all hydrodynamic coefficients within the equations governing the motion of a compartment containing liquid when the compartment has internal structural elements like radial and ring ribs. Nevertheless, there is a need to validate the reliability of these hydrodynamic coefficients, particularly the damping coefficients. To achieve this, the following section presents the results of determining the damping coefficients (logarithmic decrements) associated with the principal (first antisymmetric) and the primary symmetrical modes of fluid oscillations in a cylindrical compartment. These determinations are conducted for the two primary types of internal damping elements: radial and ring ribs located on the wall. The section also includes a comparison of these results with directly obtained experimental data.

For establishing semi-empirical relationships to determine damping coefficients, we will adhere to the Myles concept. As a starting point, we will employ a well-established ratio $\delta = \frac{\Delta E}{2E}$, (4.1)

This ratio connects the logarithmic decrement with the dissipation of oscillation energy over the period ΔE and the maximum energy of the system E. The dissipation of energy ΔE is calculated as the work done by resistance forces resulting from the motion of the fluid relative to the ribs,

$$\Delta E = \int_0^{\frac{2\pi}{\omega_n}} \int_S \frac{1}{2} c_b \rho \upsilon_n^2 \left| \upsilon_n dSdt \right| . \qquad (4.2)$$

The maximum energy *of system E* is defined as the maximum potential energy according to the formula

$$E = \frac{1}{2}\rho j s_{0n}^{2}\int_{\Sigma}\psi_{n}^{2}dS \,. \tag{4.3}$$

In equations (4.2) and (4.3), s0n represents the amplitude of fluid oscillations on the cavity wall for the respective oscillation mode, while υn denotes the rate of these oscillations. Additionally, ψn corresponds to the shape of the free liquid surface associated with the particular mode of oscillation under consideration. For the primary (first antisymmetric) oscillation mode, we will use n = 1, and for the first symmetric mode, n = 0.

The integration in equation (4.3) is performed over an unobstructed free liquid surface. The theoretical values for the rate of liquid oscillation, υn, and the shape of the free surface, ψn, are derived from the solution of the hydrodynamic problem concerning fluid oscillations within the cavity without ribs. In this context, certain assumptions are introduced:

The height of the ribs is significantly smaller than the characteristic size of the cavity, typically the cylinder's radius.

The ribs are spaced sufficiently apart from each other, allowing them to be treated as independent elements.

Therefore, given the necessary experimental data on the support coefficients, knowledge of the solution to the hydrodynamic problem concerning fluid oscillation within the ribless cavity, and adherence to the above assumptions regarding rib height and placement, it becomes straightforward to determine the sought-after dependencies based on equations (4.1) to (4.3).

Now, we will proceed to directly establish semi-empirical relationships for a cylinder featuring radial and ring ribs. For both radial and ring ribs, our focus will be on scenarios where the liquid depth (h) is greater than 1.5 times the cylinder's radius (h > 1.5r0), allowing us to disregard the influence of the bottom

4.2 Cylinder with radial ribs (primary mode)

Let's examine a cavity in the shape of a straight circular cylinder containing k evenly spaced radial ribs on its wall. The key designations for this analysis include (Fig. 2). 4.1).

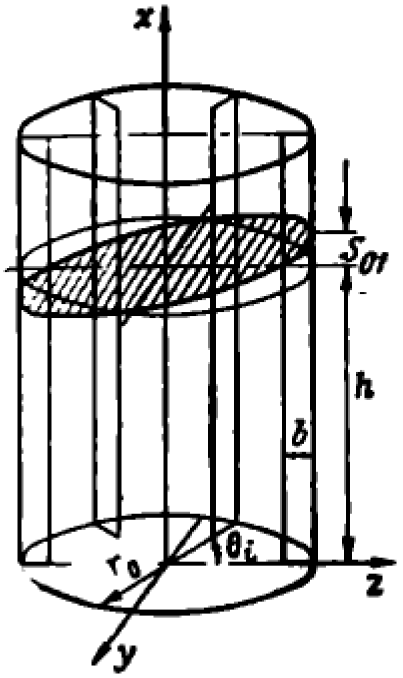


Fig. 4.1 Basic designations

The height of each rib is represented as 'b' (as shown in Fig. 4.2). It's important to note that the ribs may have varying widths and can be positioned at different distances from each other.

Based on experimental data, the relationship for the resistance coefficient associated with the ribs can be expressed within the adopted coordinate system

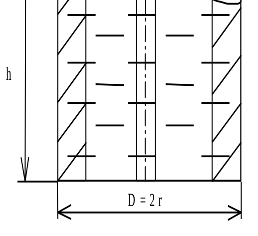


Fig. 4.2 The damping radial septum is located in the tank.

$$c_b = 19.1\left(\frac{2\pi\vartheta_{01}}{b\omega_1}\right)^{-\frac{1}{2}}\left(1 + 0.4e^{\frac{0.238(x-h)}{b}}\right) \tag{4.4}$$

To calculate the velocity, we will consider the tangential component of the velocity along the cylinder wall at the location of each rib, following the theoretical solution for fluid oscillation in the cylinder without ribsυ_1**:**

$$\vartheta_1 = \frac{\omega_1 s_{01} ch(\xi_1 \frac{x}{r})}{\xi_1 sh(\xi_1 \frac{h}{r})} \cos\theta_i \cos\omega_1 t \tag{4.5}$$

де $\omega_1 = \sqrt{\dfrac{\xi_1 th(\xi_1 h/r)}{r}}$ - frequency of the main tone of fluid vibrations in the cylinder, ξ_1 = 1,84.

Using expressions (4.4) and (4.5) and taking into account that $h > 1.5r_0$, from (4.2) we obtain

$$\Delta E = \frac{108\rho r\omega_1^2}{15\sqrt{\pi\xi_1}\xi_1^3}\left(1 + \frac{\xi_1 b}{2.5\xi_1 b + 0.138r}\right)\sum_{i=1}^{k}\left|\sin\theta_i\right|^{\frac{5}{2}} b^{\frac{3}{2}} s_{01}^{\frac{5}{2}} . \tag{4.6}$$

The shape of the free surface for the main tone of fluid oscillations in the cylinder is determined by the expression

$$\psi_1 = \frac{J_1(\xi_1 \frac{r}{R})}{J_1(\xi_1)} \sin\theta . \tag{4.7}$$

The maximum energy *of system E* is defined as the maximum potential energy according to the formula:

$$E = \frac{1}{2}\rho j s_{01}^2 \int_{\Sigma} \psi_n^2 ds$$

Substituting (4.7) in (4.1), we obtain the maximum potential energy of the system

$$E = \frac{\pi(\xi_1^2 - 1)\rho j r^2 s_{01}^2}{4\xi_1^2}\,. \qquad (4.8)$$

The sought-after semi-empirical dependence on the basis of (4.1), (4.6) and (4.8) will be written in the following form:

$$\delta = \frac{\Delta E}{2E} = \frac{14.4}{\pi\sqrt{\pi\xi_1}(\xi_{11}^2 - 1)}\left(1 + \frac{\xi_1 \frac{b}{r}}{0.138 + 2.5\xi_1 \frac{b}{r}}\right)\sum_{i=1}^{k}\left|\sin\theta_i\right|^{\frac{5}{2}}\left(\frac{b}{r}\right)^{\frac{3}{2}}\left(\frac{s_{01}}{r}\right)^{\frac{1}{2}}. \qquad (4.9)$$

In the case of edges of different heights in this formula, you need to change the b tob_i and put the sum sign in front of the parenthesis.

4.3 First symmetric mode in a cylinder with ribs

Analogous relationships apply for the first symmetrical mode of oscillations (n = 0). The shape of the free liquid surface in this case is determined by the expression of

$$\psi_0 = \frac{J(\xi_0 \frac{r}{r_0})}{J_0(\xi_0)}\,, \qquad (4.13)$$

де ξ_0=3,83- The first nonzero root of the equation $\frac{dJ_0(\xi)}{d\xi} = 0$.

The profile of the shape of the free surface of the readings in Fig. 2. 4.3.

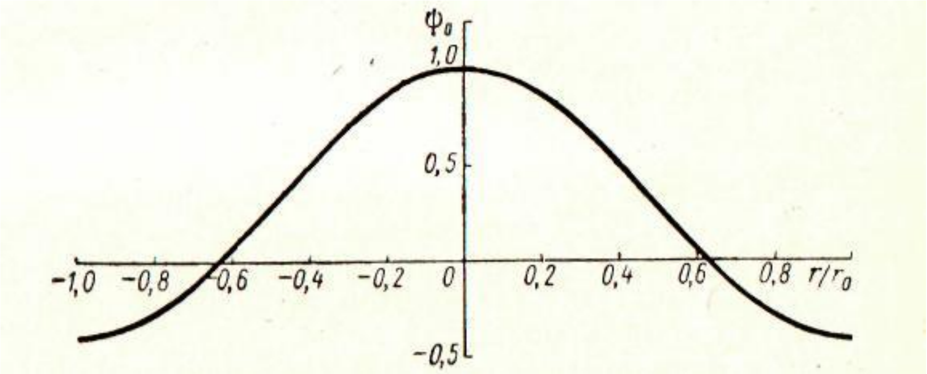


Fig. 4.3 Profile of the form of a free surface at fluctuation of liquid in the cylinder according to the first symmetrical tone

Substituting (4.13) in (4.3), we find the maximum energy of the system

$$E = \frac{1}{2}\rho j r_0^2 s_{00}^2 . \tag{4.14}$$

The dissipation of energy for the period is determined on the basis of expression (4.2), while assuming that the liquid is deep (h>1,5r_0):

$$\Delta E = \frac{8}{3}\pi\rho r_0 b \omega_0^2 s_{00}^3 c_b e^{-3\xi_0 \frac{d}{r_0}} . \tag{4.15}$$

heres_{00} — amplitude of fluid vibrations on the wall. For the speed of υ_0 in (4.2) the corresponding theoretical dependence for the cylinder without edges is adopted

$$\upsilon = s_{00}\omega_0 e^{-\xi_0 \frac{d}{r_0}} \cos\omega_0 t . \tag{4.16}$$

Using the expression for resistance coefficients (3.33) - (3.34) and substituting (4.14) and (4.15) in (4.1), obsessedwith the search for semi-empiricin the dependentandsty for the cylinder with radial ribs:

$$\delta = \sum_{i=1}^{k} \left|\sin\theta_i\right|^{\frac{5}{2}} \left(\frac{b}{r}\right)^{\frac{3}{2}} \left(\frac{s_{01}}{r}\right)^{\frac{1}{2}} \tag{4.17}$$

We will model and get graphs for the cylindrical tank with radial ribs 1-5 placed in the tank Fig 4.4-4.10

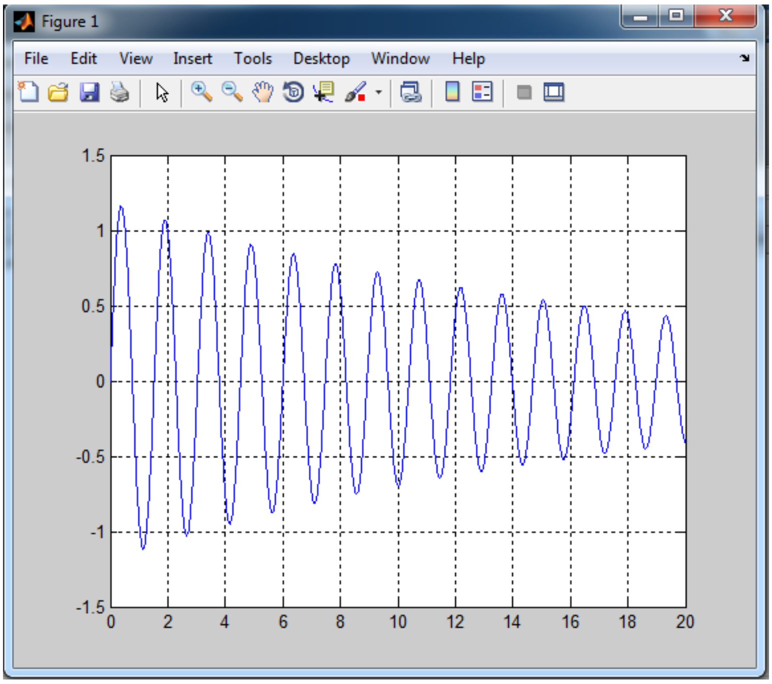


Fig 4.4 Dissipation without ribs

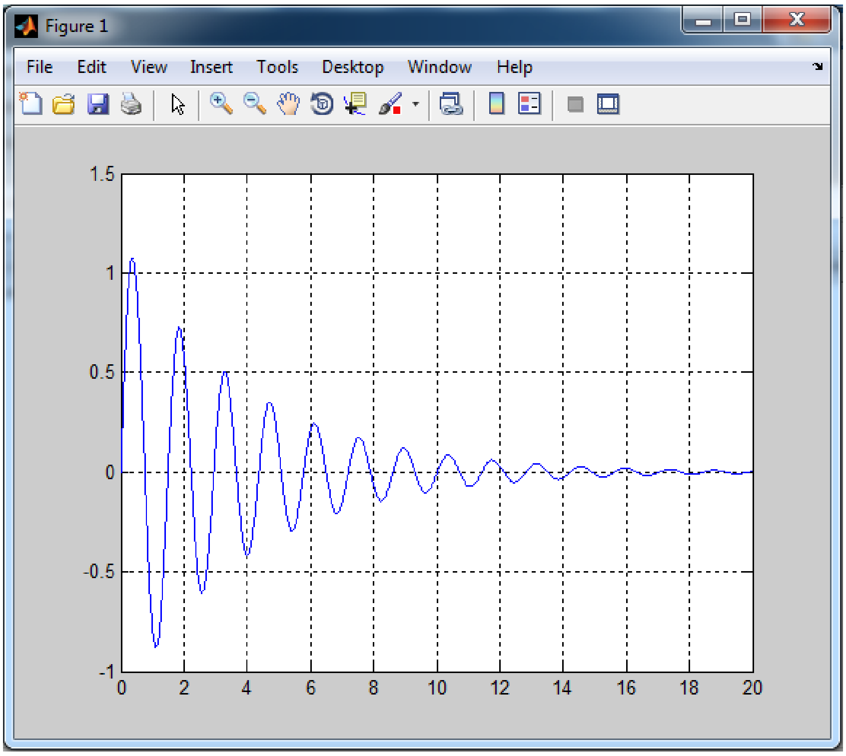


Fig 4.5 Damping 1 radial septum

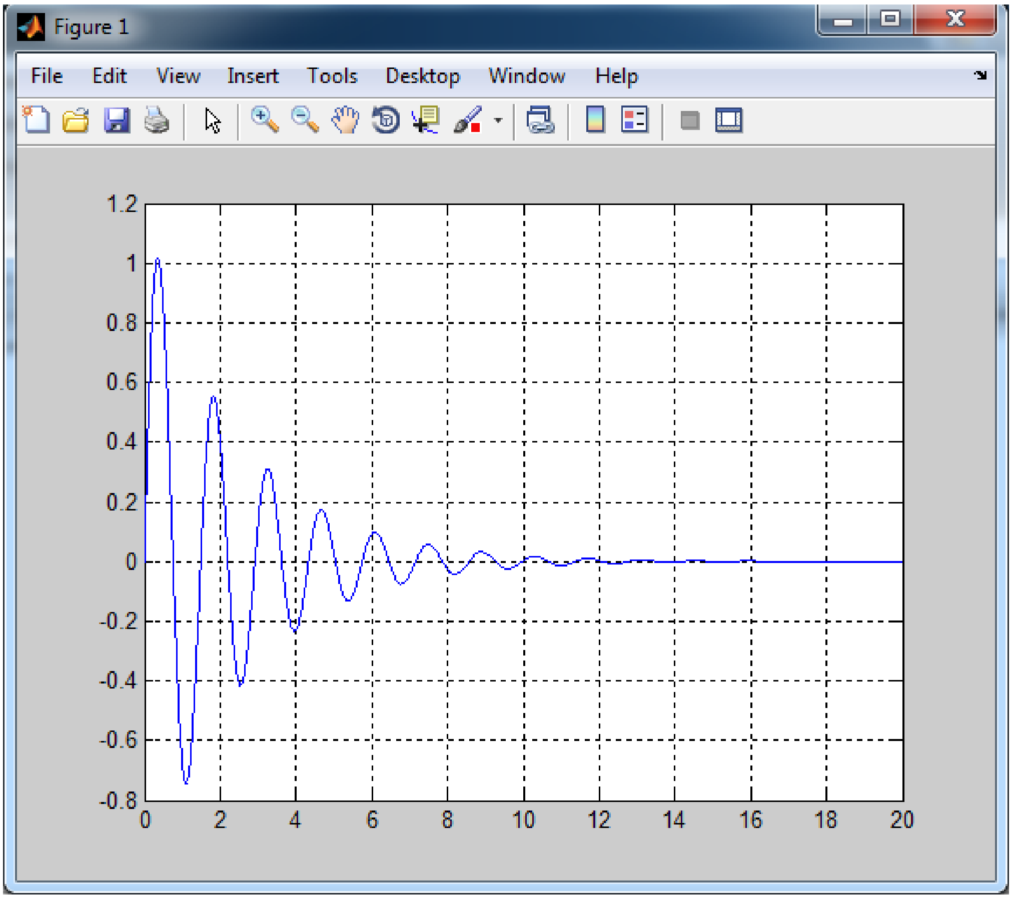


Fig 4.6 Damping 2 radial partitions

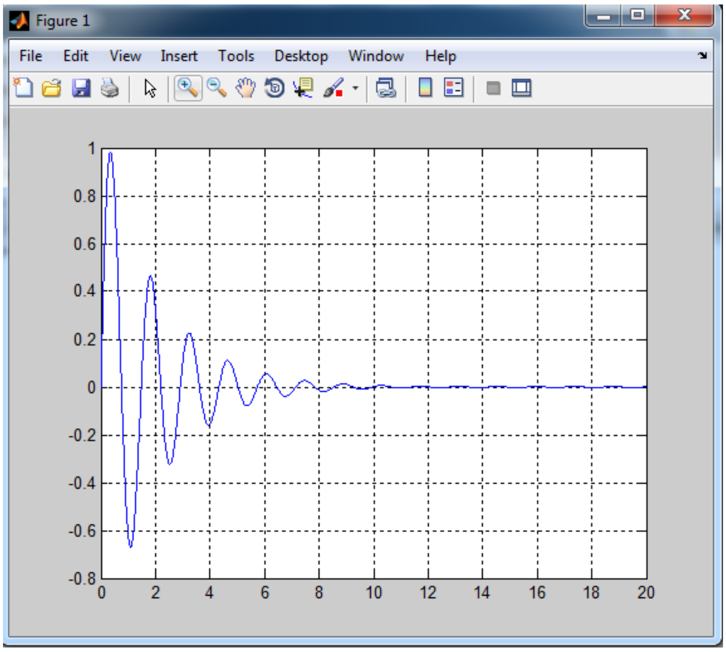


Fig 4.7 Damping 4 radial partitions

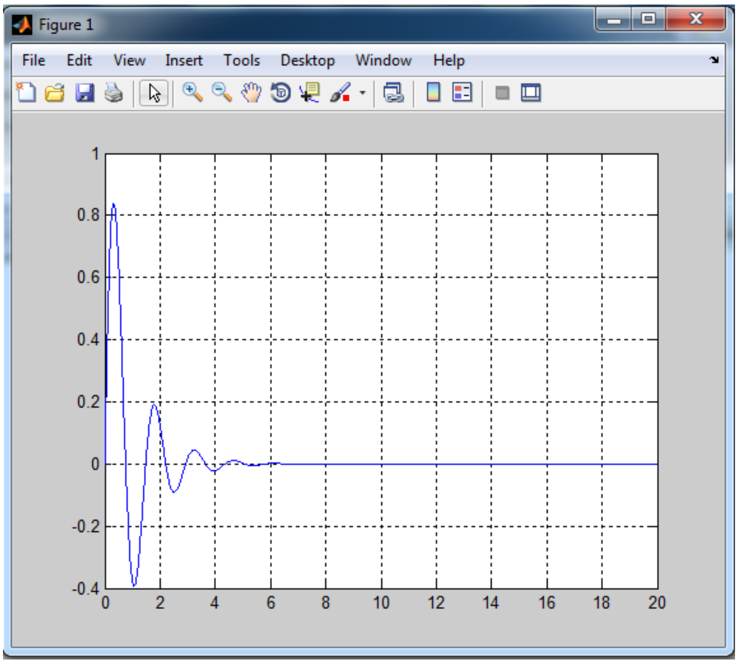


Fig 4.8 Damping 6 radial partitions

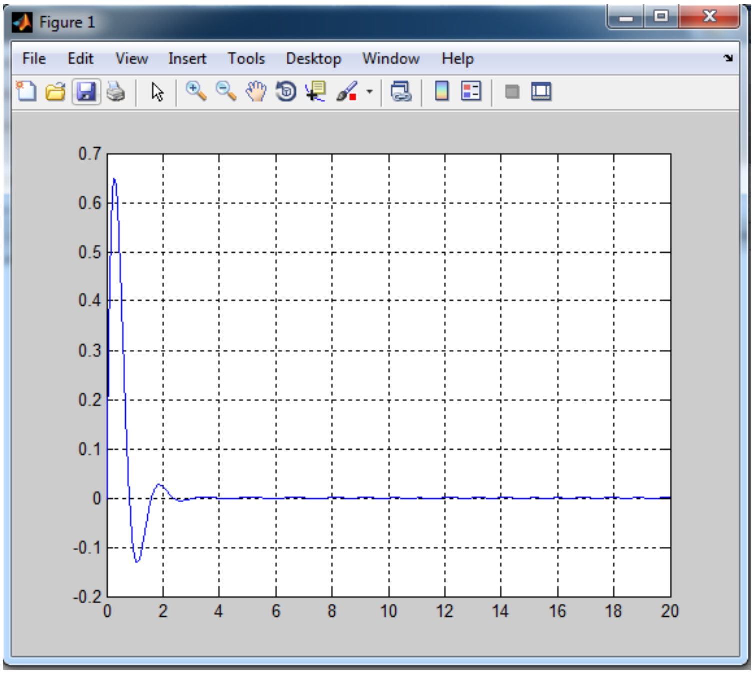


Fig 4.9 Damping 8 radial partitions

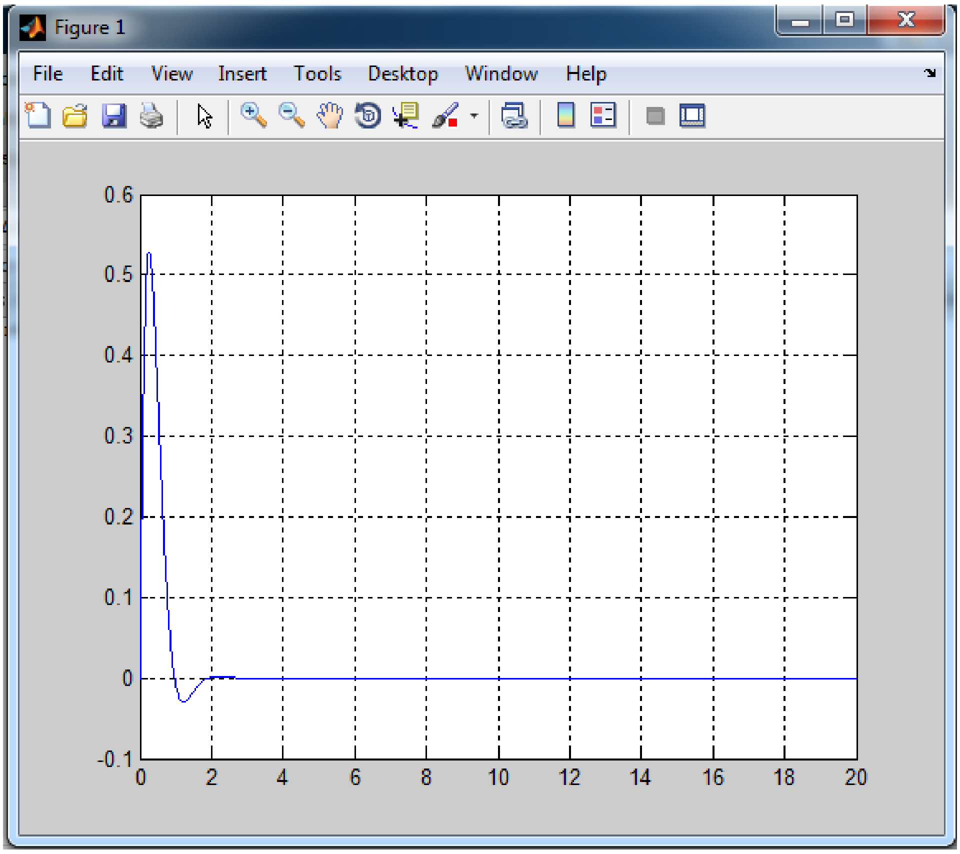


Fig 4.10 Damping 10 radial partitions

CHAPTER 6

PROTECTION OF THE ENVIRONMENT

6.1 Life cycle assessment

Life Cycle Assessment (LCA) is a systematic approach used to evaluate the environmental impacts associated with all the stages of a product's life, from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. LCA helps to quantify the ecological consequences of a product or a service and is an integral part of sustainable design and environmental management.

The key steps in a Life Cycle Assessment include:

1. Goal and Scope Definition: This step involves defining the purpose of the assessment, the product or process being assessed, and the scope of the study, including system boundaries.
2. Inventory Analysis (Life Cycle Inventory, LCI): This phase involves collecting data on the energy, material inputs, and environmental releases associated with each stage of the product's life cycle. It's a comprehensive accounting of all resources consumed and all emissions to the environment.
3. Impact Assessment (Life Cycle Impact Assessment, LCIA): Here, the environmental impacts associated with the resource use and emissions identified in the LCI are evaluated. This can include impacts on climate change, human health, ecosystem quality, and resource depletion.
4. Interpretation: This final stage involves analyzing the results from the LCIA to make informed decisions or recommendations. It helps identify areas for environmental improvements and inform stakeholders about the environmental performance of products.

LCA is widely used in product development, policy-making, and as a basis for environmental labeling schemes. It offers a comprehensive view of environmental impacts and is crucial in developing strategies to reduce the ecological footprint of products and processes.

Expanding further on the concept of Life Cycle Assessment (LCA), it's important to understand its broader implications and applications in various sectors:

Applications of LCA:

1. Product Design and Development: Manufacturers use LCA to design more environmentally friendly products. By understanding the environmental impact at each stage of a product's life cycle, they can make informed decisions about materials, design, and manufacturing processes.
2. Policy Making and Regulations: Governments and regulatory bodies use LCA to develop environmental policies and regulations. LCA provides a scientific basis for setting environmental standards and for promoting eco-friendly practices in industries.
3. Supply Chain Management: Companies apply LCA to assess the environmental impact of their supply chains. This helps in identifying 'hot spots' – areas with significant environmental impact – and in making improvements.
4. Strategic Planning and Marketing: Businesses use LCA to inform strategic planning and to communicate the environmental credentials of their products to consumers. This is increasingly important as consumers become more environmentally conscious.
5. Waste Management and Recycling: LCA is used to evaluate and improve waste management and recycling processes. It helps in understanding the environmental benefits of different waste management strategies, such as recycling, landfilling, or incineration.

Challenges and Considerations in LCA:

1. Data Quality and Availability: Accurate LCA requires comprehensive and high-quality data, which can be challenging to obtain. The availability and

reliability of data can significantly influence the outcomes of the assessment.

2. Scope and Boundaries: Defining the scope and boundaries of an LCA can be complex. It involves decisions about what stages of the life cycle to include and how to handle indirect impacts.
3. Interpretation of Results: The results of an LCA can be subject to interpretation. Different methodologies and assumptions can lead to different conclusions, making it important to be transparent about the methods used.
4. Trade-offs: LCA often reveals trade-offs between different environmental impacts. For example, a change in a product’s design that reduces greenhouse gas emissions might lead to increased water usage or vice versa.
5. Dynamic Nature of Environmental Assessment: The field of environmental science is constantly evolving. Keeping LCAs up to date with the latest scientific understanding and environmental priorities is a continuous challenge.

6.2 Description of equipment in terms of materials used, composition

Materials and Composition of the Fire Extinguisher:

1. Extinguishing Agent: The choice of extinguishing agent plays a significant role in environmental impact. Traditionally, halon was used due to its effectiveness, but it has been phased out due to its ozone-depleting properties. Modern extinguishers often use more environmentally friendly alternatives like water, foam, dry chemicals (like monoammonium phosphate), or clean agents like HFC-236fa, which have a lower global warming potential (GWP) and ozone depletion potential (ODP).
2. Container Materials: Fire extinguishers are typically made of steel or aluminum. These materials are chosen for their durability, pressure

resistance, and recyclability. The environmental impact of these materials can be mitigated through proper recycling practices at the end of the extinguisher's lifecycle.

3. Damping System Components: The damping system, essential for controlling the release of the extinguishing agent, may involve various materials like rubber for seals and gaskets, and metals or plastics for valves and hoses. The selection of these materials should consider durability to extend the lifespan of the extinguisher and the potential environmental impact at the end of their life.
4. Coatings and Paints: The outer coating or paint used on fire extinguishers not only provides corrosion resistance but also contains labeling information. The use of environmentally friendly, non-toxic paints and coatings can reduce the ecological footprint.

Environmental Considerations in Manufacturing and Disposal:

1. Manufacturing Process: The production of fire extinguishers involves energy-intensive processes, especially in metal fabrication and chemical processing for extinguishing agents. Implementing energy-efficient manufacturing practices and using renewable energy sources can minimize environmental impact.
2. Disposal and Recycling: At the end of their useful life, fire extinguishers must be disposed of properly. Components like metal canisters can be recycled, but the extinguishing agent needs careful handling, especially if it contains chemicals that could be harmful to the environment.

Sustainable Practices in Design and Usage:

1. Design for Longevity and Reusability: Designing fire extinguishers for longevity, with replaceable components like valves and damping systems, can reduce environmental impact by extending the life of the extinguisher and reducing waste.

2. Eco-Friendly Extinguishing Agents: Using extinguishing agents that have minimal environmental impact, both in terms of GWP and ODP, is crucial. Water and foam-based agents are often preferred for their low environmental impact.
3. User Training and Awareness: Proper training in the use of fire extinguishers ensures efficient use of the extinguishing agent, reducing waste and environmental harm during discharge.

In summary, the environmental protection aspect of the optimal damping system of fire extinguisher liquid involves careful consideration of the materials used in the extinguisher, the production processes, and the disposal and recycling at the end of its lifecycle. Sustainable practices in the design and selection of eco-friendly materials and extinguishing agents can significantly reduce the environmental impact of these crucial safety devices.

6.3 Environmental Impact of Life Cycle Stages

When considering the environmental impact of the life cycle stages of a fire extinguisher system with an optimal damping mechanism, it's important to evaluate each phase from production to disposal. This lifecycle assessment helps in understanding and mitigating the environmental footprint of the fire extinguisher system.

Raw Material Extraction and Processing:

- The materials used in fire extinguishers, such as steel, aluminum, rubber, and chemical agents, have to be extracted and processed. This stage often involves mining and chemical processing, which can have significant environmental impacts including energy consumption, greenhouse gas emissions, and resource depletion.

Manufacturing and Assembly:

- The manufacturing process involves shaping the metal canisters, assembling the damping system, and filling the extinguishers with the fire-suppressing agent. This stage can be energy-intensive and may involve the emission of pollutants and waste generation. The use of energy-efficient manufacturing processes and waste minimization techniques can reduce these impacts.

Distribution and Transportation:

- Transporting the finished fire extinguishers to various locations contributes to the overall carbon footprint through fuel consumption and associated emissions. Optimizing logistics and using fuel-efficient transportation can mitigate these effects.

4. Usage:

- The environmental impact during the use phase is primarily associated with the discharge of the extinguishing agent. Agents that are non-toxic, do not deplete the ozone layer, and have a low global warming potential are preferable from an environmental standpoint. Additionally, the longevity and reliability of the fire extinguisher also play a role in its environmental impact.

Maintenance and Refilling:

- Regular maintenance and periodic refilling extend the life of fire extinguishers, reducing the need for producing new units. This stage can be optimized to minimize waste and environmental impact.

End-of-Life Disposal and Recycling:

- Disposal is a critical phase, especially for extinguishers with chemical agents that need special handling to avoid environmental contamination. Metal components of the extinguisher can often be recycled, but it requires proper separation and processing. The environmental impact of disposal can be reduced through effective recycling and safe waste management practices.

In summary, each stage of the fire extinguisher's life cycle, from raw material extraction to end-of-life disposal, has distinct environmental impacts. Understanding these impacts is essential for implementing measures to reduce the ecological footprint of these safety devices. This includes choosing eco-friendly materials and extinguishing agents, employing energy-efficient manufacturing processes, ensuring efficient distribution, promoting maintenance and refilling, and facilitating recycling and safe disposal.

6.4 Environmental impact comparison devices with similar devices

When comparing the environmental impact of fire extinguishers with optimal damping systems to similar fire suppression devices, several key aspects must be considered to understand their ecological footprint comprehensively.

Firstly, the materials used in the construction of these devices play a significant role in their overall environmental impact. Fire extinguishers are commonly made from steel or aluminum, which, while recyclable, carry a notable environmental cost in terms of extraction and processing. Alternative materials used in other devices, such as composites or recycled materials, might offer lower environmental impacts, making this a crucial point of comparison.

Another critical factor is the choice of extinguishing agents. Traditional agents like halon are known for their ozone-depleting effects, whereas modern alternatives such as water, foam, or clean agents have a significantly lower Global Warming Potential (GWP) and Ozone Depletion Potential (ODP). Comparing the environmental friendliness of these agents is essential in assessing the overall ecological impact of the fire extinguishers.

The manufacturing processes employed to produce these devices also contribute to their environmental impact. Factors like energy consumption, emissions, and waste production during the manufacturing stage vary between different products. Devices manufactured using renewable energy sources or those employing waste reduction techniques might have a lesser environmental impact compared to others.

Operational life and maintenance are also key components of this comparison. Fire extinguishers with a longer lifespan, which are easier to maintain and refill, typically have a lower environmental impact over their lifecycle compared to those requiring frequent replacements or disposals.

The end-of-life disposal and recycling of these devices is another critical aspect. The ease of recycling materials used in fire extinguishers and the safe disposal methods of used extinguishing agents significantly affect the overall environmental impact. Devices that facilitate easier and safer disposal processes, particularly for those containing hazardous materials, are more environmentally sustainable.

Lastly, the efficiency of these devices in terms of energy and resource use during operation is important. Systems that require less extinguishing agent or that deploy more efficient discharge mechanisms contribute to environmental sustainability. Moreover, adherence to environmental regulations such as REACH and RoHS can also be a benchmark for comparison, with stricter compliance often indicating a lower environmental impact.

In conclusion, a comprehensive environmental impact assessment of fire extinguishers with optimal damping systems, in comparison to similar devices, involves evaluating the materials, extinguishing agents, manufacturing processes, lifespan, maintenance, disposal, operational efficiency, and regulatory compliance. This holistic approach helps in identifying the most environmentally sustainable option and in pinpointing areas for potential improvements.

6.5 Recommendations for limiting exposure

Limiting exposure to harmful elements within the context of developing and using fire extinguishers with optimal damping systems involves a series of strategic recommendations. These guidelines aim to reduce environmental impact and enhance user safety throughout the different stages of the fire extinguisher's life cycle.

Firstly, in the manufacturing stage, it’s vital to focus on reducing emissions and waste. This can be achieved by adopting cleaner production technologies, using more sustainable materials, and implementing efficient waste management systems. For instance, switching to renewable energy sources for manufacturing processes can significantly reduce carbon footprints. In addition, selecting materials that have a lower environmental impact, such as recycled metals or eco-friendly alternatives for parts of the damping system, can reduce the overall ecological burden of production.

When it comes to the extinguishing agents used in fire extinguishers, choosing environmentally friendly alternatives is crucial. Opting for agents with a lower global warming potential and zero ozone depletion potential not only minimizes environmental damage but also aligns with global environmental standards and regulations. Moreover, the development of more efficient damping systems that optimize the use of these agents can reduce the quantity required to extinguish fires, thereby limiting environmental exposure.

In terms of distribution and transportation, optimizing logistics to reduce fuel consumption can lower greenhouse gas emissions. This might involve using more efficient transportation methods or redesigning supply chains to minimize travel distances.

During the usage phase, training and awareness programs are essential. Educating users on the proper use and maintenance of fire extinguishers not only ensures safety but also helps in conserving extinguishing agents and reducing unnecessary discharges. Regular maintenance checks can also ensure the systems are functioning optimally, further reducing the risk of excessive or improper use.

For end-of-life management, encouraging recycling and proper disposal is key. Implementing take-back programs where manufacturers facilitate the recycling of old or used fire extinguishers can significantly reduce environmental pollution. Safe disposal methods for extinguishing agents, especially those that are chemical-based, should be established to prevent contamination of soil and water sources.

Lastly, ongoing research and development into more sustainable and efficient fire suppression technologies can continuously improve the environmental footprint of these systems. By staying abreast of technological advancements and integrating them into new designs, the overall exposure to harmful elements can be progressively reduced.

In summary, limiting exposure in the context of fire extinguishers with optimal damping systems involves a comprehensive approach that spans manufacturing, agent selection, distribution, usage, and disposal. By focusing on sustainable practices, efficiency, and education, the environmental and safety impacts of these systems can be significantly mitigated.

6.6 Conclusions

In conclusion, the exploration of fire extinguishers with an optimal damping system has brought forth several critical insights and recommendations, especially concerning environmental and user safety. The comprehensive analysis underscored the necessity of integrating environmentally sustainable practices at every stage of the fire extinguisher's life cycle, from manufacturing to disposal.

The research highlighted the importance of adopting cleaner and more energy-efficient manufacturing processes, using sustainable materials, and focusing on waste reduction. The selection of eco-friendly extinguishing agents with lower global warming and ozone-depleting potentials emerged as a crucial factor in minimizing the environmental impact. Moreover, the development of efficient damping systems that optimize the use of these agents was recognized as a key step towards sustainability.

Efficient logistics in distribution and transportation, aimed at reducing carbon emissions, were identified as important for limiting the ecological footprint. Equally vital is the role of training and awareness programs in ensuring the proper use and maintenance of fire extinguishers, thereby enhancing safety and reducing unnecessary environmental exposure.

The study also emphasized the significance of end-of-life management strategies, particularly recycling and safe disposal methods, in preventing environmental contamination. Continuous innovation and embracing technological advancements in fire suppression systems were acknowledged as essential for ongoing improvement in environmental performance.

Overall, the project not only contributes valuable knowledge to the field of fire safety equipment but also aligns with broader environmental objectives. It underscores the responsibility of manufacturers, users, and policymakers in adopting and promoting practices that safeguard both human life and the environment. The findings and recommendations of this study serve as a guiding framework for future developments in fire extinguisher technology, steering it towards greater sustainability and effectiveness.

CHAPTER 7

LABOR PROTECTION

7.1 Organization of the workplace of a specialist engineer

The organization of the workplace for a specialist engineer, particularly in the context of developing and testing fire extinguishers with an optimal damping system, is a crucial aspect of labor protection. This section outlines key considerations to ensure a safe, efficient, and ergonomically sound working environment.

Ergonomic Workspace Design:

- Furniture: The use of adjustable chairs and desks is essential to prevent musculoskeletal disorders. Engineers often spend long hours at their workstations, so ergonomically designed furniture can help maintain correct posture and reduce the risk of strain injuries.
- Equipment Placement: The layout of computers, monitors, and other equipment should minimize the need for repetitive movements or awkward postures. Monitors should be at eye level to avoid neck strain, and frequently used tools should be within easy reach.

Safe Handling of Materials and Equipment:

- Engineers working with fire extinguishers need to handle various materials, including chemical agents. Proper training in handling these materials, along with the use of appropriate personal protective equipment (PPE) such as gloves and safety goggles, is necessary.
- Regular maintenance and inspection of testing equipment are important to ensure that they are safe to use and functioning correctly.

Ventilation and Air Quality:

- Adequate ventilation is crucial, especially if work involves chemical agents or soldering. Ensuring good air quality reduces the risk of inhaling fumes or airborne particles that could be harmful.

Noise Control:

- In environments where testing and development may generate significant noise, steps should be taken to control noise levels. This could include soundproofing areas or providing ear protection to reduce the risk of hearing damage.

Visual and Lighting Comfort:

- Proper lighting is essential for detailed engineering work. Task lighting can help reduce eye strain, and minimizing glare on screens and work surfaces contributes to visual comfort.

Emergency Procedures and Safety Training:

- Clearly defined emergency procedures, including evacuation routes and first aid, are essential. Regular safety training ensures that engineers are aware of how to respond in different types of emergencies.

Mental Health and Well-being:

- Recognizing the importance of mental health, provisions for regular breaks, stress management, and a supportive work environment are key. This includes addressing workload management and providing resources for mental well-being.

Compliance with Health and Safety Regulations:

- The workplace should comply with all relevant health and safety regulations. Regular audits and assessments can help in maintaining compliance and identifying areas for improvement.

In conclusion, organizing a safe and efficient workplace for a specialist engineer in the field of fire extinguisher development involves careful consideration of ergonomic design, safety procedures, material handling, environmental conditions, and mental well-being. These measures not only comply with labor protection standards but also contribute to the overall productivity and well-being of the engineers.

7.2 Analysis of risk factors at the workplace

Analyzing the risk factors at the workplace of a specialist engineer, particularly in the field of fire extinguisher development with an optimal damping system, involves a comprehensive evaluation of potential hazards. This analysis should be grounded in recognized standards such as the Ukrainian State Standards (DSTU) to ensure thoroughness and compliance.

1. Electrical Hazards:

- Engineers often work with electrical components and testing equipment. Risks include electric shock, short circuits, and overloads. Compliance with DSTU 7237:2011, which outlines general requirements and nomenclature for electrical safety, is essential. Regular equipment inspections and the use of circuit breakers and insulating materials can mitigate these risks.

2. Chemical Hazards:

- Handling fire extinguishing agents or chemicals used in manufacturing processes poses risks such as skin irritation, respiratory issues, or chemical burns. Adherence to DSTU standards related to chemical handling and storage, including appropriate use of personal protective equipment (PPE), is crucial for safety.

3. Mechanical Hazards:

- Working with machinery or equipment parts can present risks like cuts, abrasions, or entanglement. DSTU standards related to machine safety and protective guards should be followed to prevent such injuries.

4. Ergonomic Risks:

- Repetitive tasks, prolonged sitting, and improper workstation setup can lead to musculoskeletal problems. DSTU 2293-99, concerning ergonomic requirements for workstations, can guide the setup of an ergonomically sound working environment.

5. Fire and Explosion Risks:

- Given the nature of the work, there is a potential risk of fire or explosions. Adhering to DSTU 7012:2009, which includes terms and definitions related to fire safety, and implementing appropriate fire safety measures including fire extinguishers, smoke detectors, and clear evacuation routes is vital.

6. Environmental Risks:

- Exposure to poor air quality, excessive noise, or inadequate lighting can impact health and productivity. Relevant DSTU standards for air quality, noise levels (such as DSTU ISO 9612:2014 for occupational noise exposure), and lighting should be applied to mitigate these risks.

7. Psychological Risks:

- Stress, burnout, and mental fatigue are significant concerns in high-pressure engineering environments. While DSTU standards may not explicitly cover mental health, incorporating best practices for stress management and a supportive work environment aligns with general health and safety principles.

In conclusion, a thorough analysis of workplace risk factors for a fire extinguisher development engineer must consider a broad spectrum of potential hazards. Adherence to DSTU standards provides a structured and compliant approach to identifying and mitigating these risks, encompassing electrical, chemical, mechanical, ergonomic, fire, environmental, and psychological aspects to ensure a safe and healthy work environment.

7.3 Analysis of risk factors at the workplace

In a workplace where a specialist engineer works with advanced devices, several risk factors need to be considered and managed effectively. These risks encompass a range of potential hazards that could affect the safety and well-being of the engineer.

Electrical Hazards: one of the primary risks in such a setting is electrical hazards. Working with electronic components and circuitry can expose engineers to the risk of electric shocks, short circuits, and other electrical injuries. This risk is heightened if the workspace is not properly equipped with safety measures like circuit breakers or insulating materials.

Chemical hazards: if the work involves soldering or the use of chemicals, there are risks associated with exposure to harmful substances. Inhalation of fumes from soldering or chemical solvents can pose health risks, and direct contact with these substances can cause skin irritation or burns.

Ergonomic risks: engineers often spend long hours at workstations, leading to ergonomic risks such as repetitive strain injuries, back pain, and eye strain. Poorly designed workspaces that do not support proper posture or require repetitive motions can exacerbate these issues.

Fire hazards: the use of electrical equipment and potentially flammable materials like certain chemicals can increase the risk of fire. Inadequate fire safety measures can turn minor incidents into major emergencies.

Noise hazards: if the workspace includes noisy equipment like testing machinery or 3D printers, prolonged exposure to high noise levels can lead to hearing impairment or increased stress levels.

Tripping and falling hazards: A cluttered or poorly organized workspace can lead to physical injuries caused by tripping over loose cables, equipment, or other obstacles.

Mental health risks: the demanding nature of engineering work, combined with tight deadlines and potentially long hours, can lead to stress, burnout, and other mental health issues.

Environmental risks: especially in laboratories or workshops, there's a risk of negatively impacting the environment through improper disposal of electronic waste or chemicals, or inefficient use of resources.

To mitigate these risks, it's essential to implement comprehensive safety measures, including regular safety training, proper workspace design, use of personal protective equipment, and adherence to health and safety protocols. Regular risk assessments and updates to safety procedures are also crucial to adapt to changing work conditions or new technologies.

7.4 Fire Security

Fire security in a workplace specializing in the development and testing of fire extinguishers with optimal damping systems necessitates a comprehensive and multi-layered approach. This approach encompasses conducting thorough risk assessments, implementing preventive measures, ensuring the presence of effective detection and suppression systems, and establishing robust training and emergency protocols.

The initial step involves a detailed risk assessment to identify potential fire hazards inherent in the work environment. Key areas of focus include electrical equipment, the storage and handling of flammable materials, and the specific risks associated with the chemical agents used in fire extinguishers. Based on this assessment, appropriate preventive measures must be put in place. This includes regular maintenance checks of electrical devices, proper storage solutions for combustible materials, and maintaining a clean, clutter-free workspace to minimize the risk of accidental fires.

Equally crucial is the installation and maintenance of fire detection and suppression systems. Smoke detectors, heat sensors, and an accessible array of suitable fire extinguishers and sprinkler systems should be strategically placed throughout the facility. Regular inspections and maintenance of these systems ensure their functionality and readiness in case of a fire outbreak.

Training and safety protocols form another vital component of fire security. Employees should receive regular training on fire safety practices, including the correct use of fire extinguishers and identification of different fire types. Additionally, clear evacuation plans should be established and communicated to all staff members, with regular drills conducted to reinforce this knowledge. This ensures that in the event of a fire, employees can respond swiftly and efficiently, minimizing risks and damages.

Lastly, an emergency response plan should be well-defined and readily accessible to all employees. This plan should outline specific actions to be taken during a fire, including procedures for alerting emergency services and safe evacuation strategies. Special attention should be given to handling potential chemical hazards that may arise during fire incidents. Furthermore, designated personnel should be trained in first aid and emergency response to handle any immediate injuries or accidents.

In summary, ensuring fire security in an engineering environment dedicated to fire extinguisher development involves a systematic and proactive approach. By combining risk assessments, preventive strategies, effective detection and suppression systems, comprehensive training, and emergency preparedness, a safe and secure workplace can be maintained, effectively safeguarding both personnel and property

7.5 Organizational and technical measures to combat harmful and dangerous factors

Organizational and technical measures are essential in combating harmful and dangerous factors in workplaces, especially in settings focused on the development and testing of fire extinguishers with optimal damping systems. These measures aim to create a safer work environment, minimize risks, and ensure the well-being of employees.

Organizational Measures:

Effective management of workplace safety begins with a clear organizational strategy. This involves conducting regular risk assessments to identify potential hazards in the workplace, such as exposure to chemical agents, electrical risks, or mechanical hazards. Based on these assessments, safety protocols and guidelines should be developed and implemented. These protocols might include procedures for safely handling chemicals, guidelines for operating and maintaining machinery, and best practices for ergonomic workstation setup.

Another key organizational measure is employee training and awareness programs. Regular training sessions should be conducted to educate employees on safe work practices, emergency response, and the proper use of safety equipment.

Creating a culture of safety where employees are encouraged to report potential hazards and actively participate in safety discussions can significantly enhance overall workplace safety.

Technical Measures:

Alongside organizational strategies, technical measures play a crucial role in ensuring a safe working environment. This includes the provision and proper maintenance of personal protective equipment (PPE) such as gloves, safety goggles, and ear protection, tailored to the specific hazards of the workplace. The ergonomic design of the workspace is also critical. Workstations should be arranged to minimize the risk of musculoskeletal problems, with adjustable furniture and proper placement of tools and equipment to avoid strain injuries.

In environments where chemical hazards are present, adequate ventilation systems are essential to maintain good air quality and prevent the inhalation of harmful substances. Implementing technical controls like fume hoods or localized exhaust systems can effectively reduce exposure to hazardous fumes.

Additionally, safety features in machinery and equipment, such as emergency stop buttons, guards on moving parts, and proper electrical insulation, are vital technical measures. Regular maintenance and inspection of equipment ensure that these safety features are always in optimal condition.

Emergency Preparedness:

Preparation for emergencies is another critical aspect of combating harmful and dangerous factors. This includes having a well-established emergency plan, accessible fire safety equipment, clearly marked evacuation routes, and trained personnel capable of responding to different types of emergencies, including chemical spills or fire outbreaks.

In conclusion, a combination of organizational and technical measures is required to effectively combat harmful and dangerous factors in the workplace. By systematically identifying risks, implementing appropriate safety protocols, ensuring the use of proper equipment, and preparing for emergencies, workplaces can significantly reduce the occurrence of accidents and injuries, ensuring a safer and healthier environment for all employees.

7.6 Conclusions of chapter

In conclusion, the comprehensive approach to addressing organizational and technical measures for combating harmful and dangerous factors in the development and testing of fire extinguishers with optimal damping systems is paramount to ensuring workplace safety. The implementation of thorough risk assessments forms the foundation of this approach, allowing for the identification and mitigation of potential hazards specific to this field, including chemical, electrical, and mechanical risks.

The importance of organizational measures, particularly in the form of robust safety protocols and employee training programs, cannot be overstated. These measures foster a culture of safety awareness and proactivity, ensuring that all employees are well-versed in best practices for handling equipment, chemicals, and emergencies. Regular training and open communication channels also contribute to an environment where safety concerns are promptly addressed and managed.

On the technical front, the provision and maintenance of personal protective equipment, the ergonomic arrangement of workspaces, and the implementation of safety features in machinery and equipment play a crucial role in protecting employees from occupational hazards. These measures, alongside effective emergency preparedness plans, equip the workplace to respond efficiently and effectively to incidents, thereby minimizing risk and safeguarding personnel.

Ultimately, the blend of organizational and technical strategies creates a holistic safety framework. This framework not only adheres to regulatory standards but also goes above and beyond to ensure the highest level of safety in the workplace. As the field of fire extinguisher development evolves, continuously updating and refining these safety measures will be essential to meet new challenges and maintain a safe, productive work environment.

CONCLUSIONS

In conclusion, this diploma thesis on "Optimal Damping System of Fire Extinguisher Liquid" represents a significant contribution to the field of fire safety and engineering. The research undertaken provides valuable insights into the development of more effective, efficient, and environmentally friendly fire extinguishing systems. By focusing on the damping mechanism in fire extinguishers, the study addresses crucial aspects of rapid and controlled discharge of extinguishing agents, which is fundamental in enhancing the effectiveness of fire suppression.

Furthermore, the comprehensive analysis of the environmental impact, encompassing the entire lifecycle of the fire extinguisher from production to disposal, underscores the importance of environmental stewardship in the field of fire safety equipment. The thesis also provides practical recommendations for workplace safety and handling, emphasizing the need for proper training and risk management in environments where fire extinguishers are developed and tested.

The findings of this study have important implications for the future of fire safety equipment. They pave the way for further research and development in the field, particularly in creating fire extinguishers that are not only more effective but also environmentally responsible and safer for users. The study’s alignment with current technological advancements and environmental considerations ensures its relevance in addressing the needs of modern fire safety challenges.

In essence, this thesis represents a comprehensive and forward-thinking approach to improving fire extinguishing systems. It contributes valuable knowledge to the domain of fire safety engineering and opens new avenues for innovation and development in creating safer and more sustainable fire suppression solutions.

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