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на здобуття ступеня магістра

за освітньо-професійною програмою «Літаки і вертольоти»

зі спеціальності 134 «Авіаційна та ракетно-космічна техніка»

на тему: «Герметичність авіаційних конструкцій»

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ЗАТВЕРДЖУЮ

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«___»_____________2022 р.

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2. Термін подання студентом дисертації _____12.2022 р.

3. Об’єкт дослідження Герметичність окремих систем авіаційних конструкцій.

4. Вихідні дані Заклепувальні, болтові та нікельні з'єднання, паливні баки-кесони, фюзеляж.

5. Перелік завдань, які потрібно розробити

5.1. Аналіз існуючих методів неруйнівного контролю авіаційних конструкцій та систем.

5.2. Авіаційні конструкції, що підлягають контролю на герметичність, та методи течошукання. Мета та задачі дослідження.

5.3. Контроль герметичності паливної системи та фюзеляжу з використанням методу проникаючих речовин.

5.4 Розробка комбінованих методів контролю герметичності авіаційних конструкцій з використанням капілярного та магнітного контролю.

5.5 Розвиток методу контролю герметичності авіаційних конструкцій з використанням ультразвукових течошукачів.

5.6. Розробка і виготовлення конструкції портативного ультразвукового течошукача.

6. Орієнтовний перелік графічного (ілюстративного) матеріалу

6.1. Огляд літератури. Мета та задачі дослідження.

6.2.Теоретичні основи контролю на герметичність авіаконструкцій.

6.3 Результати експериментальних досліджень методу проникаючих речовин.

6.4. Результати дослідження комбінованих методів контролю.

6.5.Результати розробки і виготовлення конструкції портативного ультразвукового течошукача.

7. Орієнтовний перелік публікацій

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АНОТАЦІЯ

Актуальність теми обумовлена необхідністю організації безпечних умов експлуатації літальних апаратів. Ресурс аерокосмічної техніки безпосередньо пов'язаний з попередньою історією конструювання, виробництва та технічної діагностики виробів. Методи неруйнівного контролю авіаційних та ракетних конструкцій забезпечують врахування ресурсних вимог в процесі конструювання та експлуатації виробів.

У цій дисертації проаналізовано існуючі конструкції та системи контролю герметичності літака з їх теоретичними основами, перевагами та недоліками. Класифікуючи авіаційні конструкції та системи, які є об’єктами контролю герметичності, у дисертації аналізуються вимоги та призначення до них. Далі в якості прикладу береться метод проникнення, описується розробка та випробування цього методу повітронепроникності. Між тим, капілярні та магнітні методи та ультразвукові методи включені. Нарешті, описується портативний ультразвуковий течешукач, включаючи його розробку, дизайн і виробництво.

Наукова робота складається з основної частини, яка включає вступ, 6 розділів, 28 таблиць, 42 рисунки, висновки, 45 використаних наукових джерел та додатки. Загальний обсяг роботи 129 сторінок.

Ключові слова: *неруйнівний контроль, технічне обслуговування, капілярний контроль, ультразвуковий контроль*

ANNOTATION

The relevance of the work is related to the need to organize safe conditions for the exploitation of aircraft. The resource of aerospace technology is directly connected to the previous history of design, production and technical diagnostics of products. Methods of non-destructive control of aircraft ensure that resource requirements are taken into account in the process of design and operation of products.

This dissertation analyzes aircraft tightness control of existing constructures and systems with their theoretical foundations, advantages, and disadvantages. By classifying aircraft structures and systems, which are the subjects for air tightness control, this dissertation analyzes their requirements and purposes. Then it takes the penetrant method as an example, describing the development and test of this air tightness method. Meanwhile, the capillary and magnetic methods and ultrasonic methods are included. At last, a portable ultrasonic leak detector is described, including its development, design, and manufacture.

The scientific work consists of the main part, which includes an introduction, 6 chapters, 28 tables, 42 figures, conclusions, 45 used scientific sources and appendices. The total volume of the work is 129 pages.

Keywords: *nondestructive detection, maintenance, capillary testing, ultrasonic testing*

CONTENT

LIST OF CONDITIONAL DESIGNATIONS

NDT Non-destructive testing

TC Tightness control

UT Ultrasonic Testing

PZT piezoelectric sensor

UPI Ultrasonic propagation imager

NDE Non-destructive evaluation

CDM Capillary testing method

CM Composite material

DULD Directivity-based ultrasonic leak detector

TDE Time delay estimation

INTRODUCTION

The residual life of aerospace technology is determined by the state and is directly related to the previous history of production and operation of the structure. Non-destructive testing (NDT) is an important element of the industrial safety system, which is performed for the purpose of examination of production facilities. Under the TC (Tightness control) is understood the verification of compliance of the object with the technical requirements without violating the suitability of the object for use.

The development of the aviation industry, vehicles, as well as the operation of structures in difficult conditions (high temperatures, humidity, pressure, radiation), leads to the need, firstly, to create new technological opportunities to control their safe operation, and secondly, in analytical devices and materials that have extraordinary properties and technical diversity for use. The probability of man-made accidents in the operation of high-capacity aircraft, unmanned aircraft largely depends on the availability and effective organization of the TC system, and especially on the creation of a perfect fleet of TC based on the achievements of modern physics, chemistry, materials science, electronics and computing. techniques.

The main feature of defectoscopy is the creation of environmentally friendly means of detecting defects, which begin the destruction of structures. It is clear that effective methods and diagnostic tools depend on a fleet of modern devices that perform analytical measurements to ensure the specified parameters of the technological process, and for the timely detection of defects in non-destructive testing. These devices must have high metrological characteristics and be characterized by a wide range of purposes and a wide variety of technical and consumer characteristics. Therefore, the task of creating effective methods and technical means for defectoscopy will always remain relevant. Monitoring and timely elimination of the causes of emergencies makes it possible to reduce technical risks.

The work aims to provide a systematic data of the methods of control of aircraft and the detection of damage to structures that reduce their service life.

The main attention is paid to methods and means of analyzing the state of aerospace structures, assessing the advantages and disadvantages of their use, optimizing the choice of non-destructive testing during the diagnosis of the aerospace structure and control conditions.

1. Analysis of existing methods of air tightness control of aircraft structures and systems. Their theoretical foundations, advantages and disadvantages.

Nowadays, Nondestructive Testing (NDT) plays an essential part in aircraft maintenance. Also, tightness control as a part of NDT is of great significance. To ensure the proper operation of the aircraft, the leakage should meet the given indicators from the design. Therefore, the methods that indicate whether there is a leakage and its location are of great importance in aircraft maintenance. It does not mean there is no leakage at all. It is almost impossible and inefficient to make a plane without any leakage.

However, due to the particularity of Nondestructive Testing, various methods may be particularly suitable for some applications and have little or no value in other applications. Therefore, testers must choose the proper Nondestructive Testing methods and technologies.

The following table.1 shows the main methods and sensitivity in various aircraft tightness control methods. These methods will be further elaborated on later, including their principles, advantages, and disadvantages.

Testing Method	Leak detection thresholds of different methods (mbar l/s)
Bubble test	$10^{-3}\ to\ 10^{-5}$
He sniffer	10^{-8}

Halogen detector	10^{-7}
Pressure decay & Vacuum decay	10^{-3} to 10^{-4}
Acoustical	10^{-4}
Spark tester	10^{-3}
Thermal conductivity	10^{-6}
Radioisotope	10^{-11}
Radiographic Testing	10^{-6}
Dye penetrant	10^{-5}
Ultrasonic testing	10^{-3}

Tabel.1

1.1 Bubble test

The basic principle of this method consists of creating a pressure differential across a leak and observing for bubbles in a liquid medium located on the low-pressure side. The sensitivity of the method is dependent on the pressure differential, the gas used to create the differential, and the liquid used for testing. As long as the pressure differential can be maintained across the area to be tested, this method can be applied. [1]

Furthermore, the bubble will come out from the leak through the liquid and indicate the leak's location. The liquid should not damage the test part, which can be the water with a wetting agent, methanol, alcohol, and mineral oil. As for how to generate the pressure difference, the method can be pressurizing on one side, vacuuming on one side, or heating to increase the gas pressure. There are also some gas options, including air and He.

The advantages of the bubble test are apparent, which is one of the simplest and most economical tests. However, there are still some disadvantages to the method. The bubble test takes more quality rather than quantity into consideration. The operation must be shut down to pressurize the system. At the same time, the generation of bubbles takes time. It is hard to calculate the generation time of bubbles, which relates to too many factors. It could lead to using a shorter time to miss bubbles. With a shorter time, it is also easier to miss the other leaks in the same detection. Also, the impurities in the liquid will block leak holes, which interferes with detection.

1.2 He sniffer

In recent years, with the He sniffer method widely used in aviation, the practice has proved that the He sniffer method is a practical leak detection technology in the manufacturing and maintenance process of aircraft structural fuel tanks. This leak detection method is safe and convenient, significantly shortens the fuel tank's repair time, reduces the labor intensity of employees, and improves the repair quality of the fuel tank. In a well-ventilated environment, the concentration of helium is constant. Fortunately, there is only a very low concentration of helium naturally present in the atmosphere. The background noise caused by helium in the atmosphere can be eliminated by zero calibration for the instrument during the test. At the same time, some materials will also absorb helium and release it, which should be paid attention to during the test.

One of the tiniest and most inert gas molecules is helium, which makes it easier for the gas to leak from the leakage. It also will not react with any of the components in the test part. Most helium leak testing applications employ a mass spectrometer to find the gas.

In addition to high sensitivity, this method also has the advantages of a wide application range, accurate positioning and quantification, non-toxicity, safety, and fast reaction speed. However, due to this extreme sensitivity, sometimes the permeation of helium through many elastomers (O-rings, gaskets, seals) in a given part or system will distribute the result.

Fig. 1 The He sniffer

1.3 Halogen detector

The halogen detector method uses two platinum electrodes containing potassium and sodium impurities to emit numerous potassium and sodium ions in a halogen atmosphere. With the increasing ions, it is possible to measure halogen concentration. Especially at low halogen partial pressures, the halogen sniffing reaction is linear.

When sniffer tests are being conducted on large objects, sniffing or scanning should proceed from the highest point to the lowest point in the system because refrigerant gases are heavier than air. [4]

Also, the accuracy of this method is influenced by many factors, which include smoking in the working area and some materials absorbing the halogen gas. In high temperatures, some gas like R-12 will break down into toxic gas, which harms human health. So, a well-ventilated working environment is needed.

1.4 Pressure decay & Vacuum decay

These two methods are similar to each other. The pressure decay method fills the container with dry gas, such as nitrogen or other dry gas. The pressure decay indicates the leakage reaching a target pressure in the container over a set period.

Moreover, the vacuum decay method creates a vacuum condition inside the container to indicate the leakage situation with vacuum decay over a set period. For the pressure decay method, the calculation of integral leakage can describe as follows:

$$Q = \frac{V \cdot (P_1 - P_2)}{\Delta t}$$

For the vacuum decay method, the calculation of integral leakage can also describe as follows:

$$Q = \frac{V \cdot (P_2 - P_1)}{\Delta t}$$

For the pressure decay method, the test can be performed very fast with accurate results. Meanwhile, this method is also sensitive and can calculate the leak rate based on pressure or vacuum, which provides a simple and highly effective leak test method.

However, the larger the part, the longer the cycle time required to achieve an accurate test result.

To the vacuum decay method, most advantages and disadvantages are similar. However, vacuum leak testing can provide better repeatability than pressure decay testing because it is less sensitive to environmental variables created by temperature changes. A vacuum leak detector often requires less time to reach a stable test pressure, is less susceptible to the potential instability of tested parts, and offers shorter cycle times than tests in many pressure decay applications.

1.5 Acoustical

Sound waves can be divided into infrasound, sound waves, and ultrasonic waves by the frequency of sound that people can feel as a dividing line. Analogously, the acoustical method also includes acoustic emission (AE) testing and ultrasonic testing (UT) methods.

Acoustic emission testing is a non-destructive testing technique that detects and monitors the release of ultrasonic stress waves from localized sources when a material deforms under stress. It works by mounting small sensors onto a component under test. The sensors gather sound waves and submit them to the processor. With the growth of the damage, the changed acoustic emission could be detected. The technique globally monitors a component for defects, allowing large structures and machines to be monitored while in operation with minimal disruption, unlike destructive testing. By using multiple sensors, acoustic emission sources (and hence the damage) can be located. Through signal analysis, the presence of different source mechanisms can also be determined.

The acoustical method has some specific advantages, which include the following:

1. Extensive kinds of damage detection, including fiber breakages, friction, impacts, cracking, delamination, and corrosion in their early stages.
2. The ability to monitor during the operation remotely
3. Non-invasive

4. The ability to detect the place where it is hard to access

However, there are also some disadvantages:

1. Need for other further detections to fully diagnose issues
2. Disability to detect the existing problems
3. Usually, more time than other NDT methods

The methods of Ultrasonic Testing (UT) will be described in a more detailed way in the following chapters.

1.6 Spark tester

This leak detection method uses the principle of metal, which is easy to discharge on its tip. There are two main kinds of spark tester methods. One method is only applicable to glass systems. Another method suitable for aircraft uses the color of the gas glow discharge under low vacuum to detect. When applying or spraying a specific liquid or steam on the outside system, the spark will point to the leak and show a specific color, making it possible to find the leakage and its location simultaneously.

This table.2 shows the color of the gas glow when discharging:

Nitrogen	Pink and red
Hydrogen	Red
Helium	Yellow
Carbon dioxide	White
Argon	Blue
Neon	Red/Orange

Table.2

This method can show the leakage and its location at the same time. However, the test part has a limitation of thickness in case of burn or alteration. Also, the materials should stand the heat produced by the spark. Requirements of a seal to maintain the Argon purge and prevent Oxygen contamination is needed. Magnetic samples can cause disruption to the arc and may not be analyzed.

1.7 Thermal conductivity

Two main approaches can be applied: passive [2] and active [3]. The passive method investigates the object, which is commonly higher than the ambient. Moreover, the active method gives out heat to induce thermal contrasts.

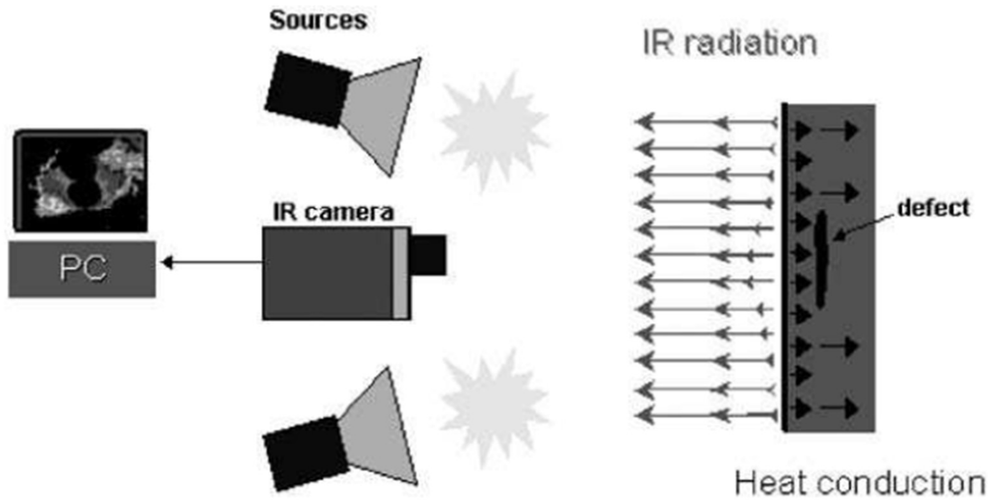


Fig. 2 The active approach in thermography. [5]

From Aircraft composites assessment by means of transient thermal NDT

The advantages of the thermal conductivity method include as below:

1. Accurate.
2. Without contact and damage
3. applicable to both local areas and large areas
4. High efficiency
5. Economy
6. Able to detect during the operation

Also, the thermal conductivity is not limited to the solid but the gas. When the gas is irradiated by infrared light, the gas will expand due to heating, resulting in sound waves, which the microphone can receive.

1.8 Radioisotope

Radioactive isotopes can also be used as indicator materials. If the mixed gas containing a small amount of radioactive material is filled into the test piece and sealed, if there is a leak, the radioactive material will leak out and be indicated by a special ray detector. This method has a wide range of uses, from small sealing devices to large containers and pipelines. The radioactive isotope method is usually used for leak detection of sealed microelectronic devices and semiconductor tubes.

In the actual leak detection work, Kr-85 radioactive material is usually selected, and the scintillation counter or Geller tube is used as the indicating instrument.

The radioactive isotope method has high sensitivity, good repeatability, simplicity, convenience, and easy operation. However, it requires skilled personnel to deal with radioactive materials, measure the intensity, and perform calibration work. The protection is also more troublesome, so the application is limited.

1.9 Radiographic Testing

The Radiographic Testing method produces the images on the film with X-rays or gamma-rays. The images are usually the same size as the tested objects. With the X-ray or gamma-ray characteristics, the very short wavelength electromagnetic radiation goes through the objects. Then the materials absorb it and obtain the images of the film of the thickness variations in the specimen, whether these are surface or internal. To get good-resolution images, the small-diameter radiation sources are used, which typically have a size range of 1 to 4 mm in diameter.

The disadvantages of this method are obvious and shown below. Its operation is complex, and it cannot get the results immediately. After the taking, the film is exposed. it's to be photographically processed (develop, wash, fix, dry) and then placed on a lighted screen for visual interpretation of the image. X-rays and gamma-rays area unit dangerous and picture-taking instrumentality should be used either within a protecting enclosure or with applicable barriers and warning signals to confirm that there's no radiation hazard to personnel. Qualified employees should use. Radiography on film may be a comparatively costly NDT methodology due to the value of the film. The larger X-ray equipment (for thick specimens) also is expensive and needs expensive protecting enclosures. Meanwhile, gamma-ray resources are more portable and lightweight, with more acceptable prices at the same time.

The methods of Dye penetrant and Ultrasonic testing will be introduced in detail in the following chapters.

1.10 Some other methods in the aircraft tightness control

Above are the main methods in aircraft tightness control. However, the aircraft tightness control methods are far more than these above. With the progress of technology and the demand for new needs, old methods are replaced and new methods are introduced.

Soumaya SALLEM et al. [6] uses the method-MCTDR (Multi-Carrier Time Domain reflectometry), which allows the device to be superimposed on the already installed systems without interfering with current signals. Moreover, the system can detect and locate precisely any abnormality or change on cable, which can lightweight the aircraft and give a more precious albert for the pilot. In most real-time non-destructive detection of aircraft for hot air leakage, thermo-sensitive cables are installed along with the air dust. The cables react to the change of temperature caused by hot air leakage. However, the method has some disadvantages, including the albert cannot show the leak localization information and some false interaction for the cable aging and junction degradation. What we do is to avoid the above problems. The main principle includes two parts, reflectometry, which is a non-destructive method based on the radar principle, and Overheat Detection System (OHDS), which is based on a eutectic salt technology sensor, with transitions from a solid to a liquid state when the temperature exceeds a threshold (an alarm set level). Meanwhile, it reduces the possibility of cable aging and junction degradation.

The author Chia, Chen Ciang, et al [7] proposed a new idea about using laser-based ultrasonic. This study proves the ability to use the laser-based ultrasonic propagation imaging system to possess non-destructive testing. The imaging system's performance was higher than that of a manual ultrasonic C-scan regarding spatial resolution and harm detectability. Most significantly, structural parts or options like spars, stringers, ribs, lugs, review windows, and even embedded PZT (Piezoelectric sensor) parts failed to affect the review adversely. Also, another finding from the review was the incidence of skin buckling that was placed perpetually between 2 riveted locations. The author believed that the laser UPI (Ultrasonic propagation imager) system is incredibly effective in guage debonding in all-out testing and complicated structures and has high potential as an on-site NDE (Non-destructive evaluation)methodology for complicated structures.

1.11 Conclusion

This chapter discussed some types of methods for aircraft tightness control in non-destructive testing, which include Bubble test, He sniffer, Halogen detector, Pressure decay & Vacuum decay, Acoustical, Spark tester, Thermal conductivity, Radioisotope, Radiographic Testing, Some other methods in the aircraft tightness control. Then their principles and advantages, and disadvantages are further discussed in this chapter. Through this chapter, we can draw the conclusion mentioned before, where various methods may be particularly suitable for some applications and have little or no value in other applications.

The methods of Dye penetrant and Magnetic particle Inspection, and Ultrasonic testing will be introduced in detail in the following chapters.

2. Classification of aircraft structures and systems with tightness control

2.1 The fuel tanks of the plane

2.1.1 The introduction to the fuel tanks of the plane

The aircraft fuel tank can be divided into three types according to its structure: bladder, rigid removable, and integral [8]. Almost all modern aircraft use the wing integral fuel tank, which is formed by a combination of skins, ribs, and spars connected by fasteners and sealed. And it is generally distributed on the wings on both sides of the aircraft. It has the advantage of making full use of the volume in the body while increasing the oil capacity without increasing the weight. [9] Currently, more and more military and civil aircraft use composite material wing fuel tank structures instead of aluminum or titanium alloy made panels and skeletons. The high incidence of oil leakage in this kind of tank structure concentrates in the place where the sealant exists, near the joints of the components in the tank structure and the fasteners used for the connection. It is key to pay close attention to these parts to find the leakage point and complete the following repair work. [10]

2.1.2 The applicable testing method and the application Scenario

In an aircraft's maintenance, the fuel tank will face various loads in its life cycle, and cracks may occur in the stress concentration area or the original defect. The leakage will lead to the loss of oil and cause accidents. The different kinds of fasteners connecting the oil tank structure may loosen. And there may be some cracks at the joints also. The sealing material may deform or even peel off due to relative creep. The seal may fail due to aging and deterioration. The occurrence of the above situations will lead to fuel leakage. Fuel leakage causes losses to operators while polluting the environment, threatens flight safety, and can even lead to severe accidents. [11]

Here takes model B737 as an example to analyze the common leakage zones. [12]

The frequent leakage points during the maintenance of the airplane are: along the S-5 skim seam, the both sides of the intersection between engine lifter bracket and the lower panel; engine lifter bracket along S-5 skin seam; central fuel tank S-5, S-9 stringer and end rib Angle box connection.

The reason for the leakage is the sealing. With the improvement of the production process, the probability of subsequent occurrence is greatly reduced. From the structural analysis, because the wing is a swept wing, swept wing is characterized by the rear beam is greater than the front beam, and the wing has a torsional deformation, in flight under the wing surface tension. Another factor is that the internal stress of the sealant also changes once for every landing and landing of the aircraft. After thousands of times of landing and landing, if the sealant has quality problems, it will also cause fuel leakage.

At the same time, the joint of the aircraft fuel tank is sealed inside the fuel tank. Therefore, the location of the internal sealant damage (the internal leakage point) will not be detected from the outside of the fuel tank. There is no symmetrical relationship between the leakage position (the external leakage point) and the leakage position (the external leakage point), which even deviates far away. [11] For example, the leakage method in the field with oil leakage and the static test is to find the external leakage point, but the internal leakage point is the actual leakage source of the fuel tank and the key to the repair work.

In the face of the large volume and high requirements for fuel tank sealing, the traditional leak detection methods use air tightness tests. These methods have the disadvantages of low accuracy, high cost, difficult quantification, and low efficiency. In addition, the oil tightness test requires a large amount of aviation kerosene to be injected into the overall fuel tank. There is a huge safety hazard under the condition of no particular oil tightness explosion-proof workshop and particular oil tightness test bench. Leakage detection with oil needs to keep the tank full of oil to detect all leakage points. Pressurization leak detection strictly complies with the maintenance manual numerical pressurization and through the bubble testing method for leak location.

In the oil tank leakage detection in the strength test, the liquid cannot be added to the oil tank at first, so the method of checking the external leakage point with oil is not applicable. The pressurization method is convenient to implement in the strength test, but it is inefficient to find the external leakage point by bubble testing, which seriously affects the test progress.

Search methods commonly used for internal leakage points are the visual inspection method, bubble testing method, external pressurization method, vacuum method, etc. [9]

The leak detection scheme in the test should not only cover the detection of internal and external leaks but also meet the detection requirements of the leakage rate. In the tank strength test, the detection requirement of the leakage rate cannot be at least that of the external field belt. Requirements for oil leak detection. Through investigation, it is found that the ultrasonic leakage and helium mass spectrometry leakage detection technology can meet the tank leakage rate's detection requirements and be suitable for the test environment under the inflatable loading mode.

2.1.3 Some practical aviation accidents with the fuel tanks

The fuel tanks' safety is essential for the airplane's maintenance, which could lead to accidents.

On November 15, 2003, a division of the Beijing Air Force organized flight training. An aircraft fuel tank burst due to fatigue cracks. The fuel leaked through a 30 cm long and 10 cm wide crack, and all leaked within a minute. Finally, the plane crashed in a field near a reservoir in North China, and the pilot jumped successfully.

On November 21, 2001, China Southwest Airlines Flight 4162 was found to have tank leakage by passengers before take-off, immediately stop take-off, and did not cause a major accident.

On September 4, 2009, a Boeing 747-400 flew from Mumbai, India, to Riyadh, Saudi Arabia, carrying 213 passengers and 16 crew. During the taxiing process, the engine (located on the left side, engine model PW4056) caught fire. The crew and passengers were evacuated through the slide. Emergency service personnel quickly controlled and extinguished the fire. During the evacuation, 21 people were slightly injured. The support fuel supply pipeline connector completely fell off due to the drop of the tie-line from the failed tie-line hole, which caused a serious fuel leakage. The leaking fuel fell on the engine and caused a fire.

2.2 The rivet joints of the fuselage

2.2.1 Introduction of the rivet joints

The fasteners and connectors have the advantages of stable and reliable connection strength, easy inspection and troubleshooting, and simplicity to process. They are suitable for connecting complex structures and different materials and have become the most widely used connection methods on aircraft structures. However, due to the existence of holes or threads, geometric inhomogeneity may occur, causing a series of mechanical effects, such as extrusion, wear, stress concentration, fatigue, etc. In turn, it can cause small gaps and fretting between the fastener and the connector, causing the surface protective layer to fall off or crack, causing moisture and other corrosive media to invade, prone to uniform corrosion, pitting corrosion, crevice corrosion, filamentous corrosion, denudation, galvanic corrosion, stress corrosion cracking, corrosion fatigue cracking and fretting corrosion, etc. [13], reducing structural strength and damage tolerance performance. Experience and test results show that 85 % of the damage in aircraft structures occurs at the connection of components. [14] The aircraft's life cycle is mainly determined by the life of the mechanical fastening connectors in critical parts. Therefore, mechanical fasteners' corrosion protection and control design technology is of great significance in improving the structural integrity and operational reliability of aircraft and reducing maintenance costs.

Rivets are nonthreaded fasteners that are usually manufactured from steel or aluminum. They consist of a preformed head and shank, which is inserted into the material to be joined, and the second head that enables the rivet to function as a fastener is formed on the free end by a variety of means known as setting.[15]

2.2.2 The analysis of the leakage caused by rivet joints

In the research Repair and Protection of Certain Naval Aircraft Corrosion, the author showed us some examples of the rivet joints of the fuselage.[14]

In the actual maintenance of a certain plane, the head of the rivet and its adjacent area have widespread corrosion phenomenon, shown in Pic.1. As for the cause analysis, in the process of the inlet assembly, the rivet did not adopt wet assembly. There was no protection measure for the hole wall after the skin was drilled. After the riveting is completed, the rivet head is flattened, and the rivet anodizing layer is damaged. The manufacturer directly enters the following process without restoring the original coating system of the rivet. When the aircraft is in regular use, the inlet part vibrates strongly, and the paint layer quickly falls off. When the paint layer is damaged, rivet head metal is directly exposed to the air, resulting in corrosion.

And another corrosion phenomenon is connected to fasteners. Cracking and peeling of the paint layer commonly occur around the fasteners on the aircraft's outer surface. It contributes to the reason that the fasteners in the parts with severe vibration are easy to loosen, causing the paint layer to fall off, and the air is in contact with the fasteners, forming a concentration primary battery in the gap of the fastener head in the operation of the airplane. In addition, the fastener does not adopt wet assembly, and the corrosion resistance is poor and prone to corrosion.

There are some maintenance covers, which are often disassembled. It leads to fasteners around the coating system quickly falling off and the metal directly in contact with the air corrosion.

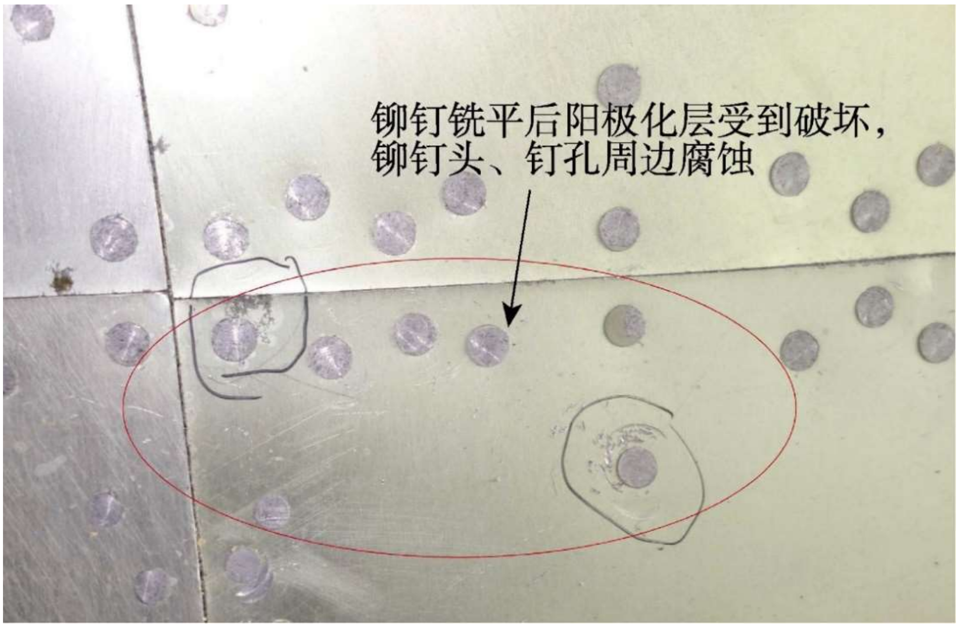


Fig. 2 Corrosion of rivet head and adjacent area [14]

Fig. 3 Corrosion around fastener holes [14]

2.2.3 Some practical aviation accidents with the rivet joints

Negligence in maintaining the rivet joints can lead to serious accidents. August 12, 1985, at 18: 12, a Boeing 747 taxied off from Haneda Airport's apron 18 to runway 16L. On June 2, 1978, the Boeing 747 damaged its tail at Osaka's Idan Airport. After the damage to the tail, Boeing did not repair it properly. When replacing a damaged pressure panel, a whole joint plate should be used to join two panels that need to be joined and fixed with three rows of rivets on top, but maintenance crews used two discontinuous joint plates, one with a row of rivets on top and the other with two rows of rivets on top. This results in a significant increase in the stress on the metal skin near the joining point and a decrease of up to 70 % in resistance to metal fatigue. During the flight, a few years after maintenance, the metal fatigue here continues accumulating due to multiple pressurization and decompression inside the cabin. According to the calculation of the post-investigator, this repair can only tolerate about 10,000 flights, and the accident flight is already the 12319th flight after maintenance. When the aircraft climbed to about 7000 km, the accumulated metal fatigue of the pressure wall panel reached the limit, and it broke because it could no longer bear the pressure difference. As a result, the cabin exploded, and the pressure was reduced. High-pressure air rushed into the aircraft's tail and blew the vertical tail directly, breaking the main hydraulic pipeline and causing the pilot to fail to control the aircraft. Eventually, the plane crashed into a mountain.

A Boeing 737-200 aircraft flew over Hawaii on April 28, 1988. Explosive pressure loss occurred during flight, the upper part of the first class part of the shell was completely damaged, and the nose and fuselage were the risks of separation and disintegration. Safe landing at the airport more than ten minutes later. The most fundamental reason is that the aluminum adhesive bonding aluminum sheet loses effectiveness. When the adhesive loses its effectiveness, water can enter the body space and then start oxidation. Because the oxidized portion is larger than the lower metal, the two sheets are forced to separate, putting additional pressure on the rivets.

At the same time, age is also a key factor in this incident. At the time, the airliner had been in use for 19 years and had flown 89,090 times, exceeding the 7,500 flights expected at design time. Aging and mental fatigue cause rivets to break and skins to break.

On 10 June 1990, during a cruise of a BAC-111, a glass window near the captain exploded, causing the captain to be sucked out of the aircraft. One of the flight attendants clutched his legs while the co-pilot made a safe emergency landing. The captain was suspended from the cockpit for 21 minutes before being taken to hospital and survived. The window burst suddenly because a maintenance technician used a non-size screw during maintenance.

2.3 The hydraulic systems of the aircraft chassis

2.3.1 The introduction of the hydraulic systems of the aircraft chassis

The aircraft classis's hydraulic system is a complete set of devices that takes oil as a working medium and drives actuators by oil pressure to complete specific operations. [16] To ensure the reliability of the hydraulic system, especially to improve the reliability of the hydraulic power source of the flight control system, most modern aircraft are equipped with two or more sets of independent hydraulic systems. [17] They are called public hydraulic systems and assist hydraulic systems. The utility hydraulic system is used for retracting the landing gear, flaps, and reducer plates, steering the front wheel, driving the windshield wiper and the hydraulic motor of the fuel pump; also used to drive part of the aileron, elevator (or fully moving horizontal tail) and rudder booster. [18] The booster hydraulic system is only used to drive the booster and damping steering gear of the above flight control system. The booster hydraulic system itself can also contain two independent hydraulic systems.

With the continuous iterative development of aircraft models, the requirements for aircraft handling and maneuverability are getting higher and higher, and the requirements for aircraft space utilization and weight reduction are becoming more and more stringent. The working pressure of the aircraft hydraulic pipeline system is gradually increased from the original 21MPa, 28MPa to 35MPa, which poses a new challenge to the reliability of the aircraft hydraulic pipeline system. [19] At present, the failure of aircraft hydraulic pipeline systems occurs frequently and is increasing year by year, which directly affects the operation safety of aircraft. According to incomplete statistics, more than 30 % of the component failures of U. S. and Russian military aircraft are hydraulic pipeline system failures. In the development and service process of a certain type of aircraft in China, the failure problem of the hydraulic pipeline system is also serious. Statistics show that in the design and manufacturing faults, there are 1650 duct faults, accounting for 71 % of the total number of faults. [20]

The basic components of the hydraulic system include the power unit-hydraulic oil pump, control part-control valve (such as safety valve, check valve, unloading valve, ground joint), executive part-actuator and hydraulic motor, and auxiliary device (such as pump oil filter, pressure gauge, oil tank, accumulator, hydraulic pipeline), etc.

2.3.2 The analysis of the hydraulic systems in design and maintenance

The working environments of the aviation hydraulic pump are complex and changeable, which include high temperature, low temperature, damp heat, temperature shock, vibration, etc. [21] These are the working environment task profiles that the aircraft will undergo daily. Through research statistics and historical experience analysis, it is concluded that the mechanical failure of the hydraulic pump is mostly caused by fatigue failure caused by installation accuracy, material organization, and suddenly changing working environments. One of the reasons for the failure of the hydraulic pump performance is the oil pollution and wear of its own structural components. The second is the blockage of the critical parts of the pump oil pollutants.

In designing, manufacturing, and assembling aircraft hydraulic pipeline systems, the assembly of pipeline connectors is particularly important. The pipeline leakage caused by improper assembly accounts for 73.94 % of the total faults. [21] The assembly stress is too large due to the excessive assembly deviation, which will cause the fatigue fracture of the duct, which will cause great harm to the flight safety of the aircraft. On the other hand, due to the wide distribution of aircraft hydraulic pipeline systems, its vibration environment is also complex and changeable. In the hydraulic accessory compartment and engine compartment with severe vibration conditions, the leakage and rupture of hydraulic ducts are particularly prominent (767 cases, accounting for 46.5 %). [21] Vibration condition is another factor that cannot be ignored in the frequent failure of the hydraulic pipeline system. In an aircraft hydraulic pipeline system, pipeline connectors easily become the weak link of the hydraulic pipeline system because of its compact and complex structure.

2.3.3 Some practical aviation accidents with hydraulic systems of the aircraft chassis

Here are some accidents caused by the hydraulic system. All these three cases share the same cause: (1) The aircraft rudder hydraulics will be stuck when experiencing extreme temperature differences. (2) Boeing's engineer inspection test data further indicates that the rudder may be reversed.On March 3, 1991, a Boeing 737-200 carried 20 passengers and 5 crew members from Denver International Airport to Colorado Springs Airport. After arriving near the destination airport, the aircraft was allowed to land on runway 35 by the tower. As it approached the landing, it suddenly leaned to the right side and immediately stalled and rolled. Due to the sudden and insufficient approach height, the plane crashed vertically in an open space 4 miles outside the airport runway after more than ten seconds. Then it exploded and burst into flames, shattered and disintegrated, killing 25 people instantly.

On September 8, 1994, the Boeing 737-3B7 was preparing to land on runway 28R at Pittsburgh International Airport when the weather was clear. As it passed the wake of a Boeing 727, it swerved to the left at an altitude of 1830 m, 10 km from the runway, swooped out of control, and crashed into a forest in Beaver County, killing all 127 passengers and five crew members.

On June 9, 1996, a Boeing 737-2H5 jet from Trenton, New Jersey to Richmond, Virginia. When approaching the destination airport, the aircraft turns to manual control. At 4000 t altitude, the captain feels that the rudder image has a slight rightward collision. Suddenly the plane tipped to the right without warning, and the rudder went completely out of control like it was stuck. Therefore, the captain adjusts the uneven output power of the engine to restore the aircraft to horizontal flight. Soon after, the plane suddenly returned to horizontal flight on its own. The captain and co-pilot immediately checked what was wrong, but soon the plane tipped right again, deviated from the fairway, and stalled. However, the plane returned to its level again shortly after. Finally, the aircraft landed safely. Apart from one flight attendant who was slightly injured, the other passengers and crew were uninjured, and the aircraft was not damaged because the aircraft was about to land with a seat belt.

2.4 Fuselage and some relevant components

2.4.1 The cabin and flight deck pressurization in the fuselage

With the development of aviation technology, modern aircraft can fly in a wide range. The increased flight height and speed adversely affect aircraft equipment and personnel on board. To ensure the appropriate environment in the aircraft, modern aircraft, especially civil aircraft, adopt pressurized cabins, which use the environmental control system to adjust pressure, temperature, and humidity. So, there is a need to ensure air-tightness in the fuselage. However, the aircraft is only sometimes completely airtight. The vent valves and dump valves work to keep the personnel feeling comfortable and blood oxygenated. Some idea thought the completely airtight cabin and flight deck might worsen the condition when there is smoke in them. Some idea thought that the completely airtight might increase the weight of the airplane. Anyway, the Cabin and flight deck in the aircraft are partially airtight but still need some air-tightness control to keep the fundamental balance of the pressure.

2.4.2 The door of the landing gear system and other similar components in the tightness control

Apart from the hydraulic system in the landing gear system, the working environment of the landing gear in the cruising state is relatively open. The direct connection between the inside and outside of the airframe, wind, dust, and water are more likely to contact the interior of the landing gear compartment, which increases the maintenance workload and cost. Corrosion caused by poor sealing will reduce the strength, rigidity and service life of the aircraft landing gear structure, affecting the safety and reliability of the aircraft landing gear structure. Corrosion of aircraft due to high-altitude pressure loss and poor sealing often occurs.

The sealing of the aircraft door is an important guarantee to prevent air leakage or pressure loss in the cabin. For the landing gear door mechanism, air pressure seals can effectively prevent direct convection inside and outside the body, reduce the inflow of gas, delay the corrosion of components, and ensure the strength, stiffness and performance of the landing gear structure. If the seal structure design is not reasonable, it is easily to lead to seal failure, thus affecting the safety and reliability of the aircraft. With the improvement of aircraft performance, flight height and flight speed, the air tightness of the landing gear door put forward more stringent requirements. The air tightness of the landing gear door is closely related to the design of door seals, and the design of the sealing ring is the dominant factor of air tightness.

In addition, there may be a leakage in the doors and windows on the fuselage. The sealing of the door is usually designed according to the form and function of the door, which is roughly divided into three types: non-pressure door, inward opening pressurized door, and outward opening pressurized door. Fuselage openings generally penetrate the fuselage structure. The load is directly transmitted to the inside of the body, such as the boarding gate, landing gear door, emergency doors, overhaul doors, and cargo doors. Such openings have strict sealing requirements. Pneumatic seals can prevent direct convection inside and outside the body, reducing the inflow of gas. Landing gear in the cruise state of the working environment is relatively open. The body inside and outside the direct convection, wind, dust and water more easily contact the landing gear compartment, increasing maintenance workload and costs. Corrosion caused by poor sealing will reduce the strength, stiffness and service life of aircraft landing gear structure and affect the safety and reliability of aircraft landing gear structure. Corrosion caused by high-altitude pressure loss and poor sealing often occurs.

2.4.3 Some related accidents

On 10 June 1996, flight 8105 from Xiamen to Beijing was flying at an altitude of 8,000 m. The cabin was lost due to mechanical failure, causing passengers to suffer acute high-altitude hypoxia and high-altitude decompression. More than 50 passengers suffered from dizziness, headache, palpitation, shortness of breath and dyspnea.

As we all know, the crash of the U.S. space shuttle ' Columbia ' brought the issue of air tightness of the landing gear door into the public eye. Before the crash, the first problem exposed was the temperature anomaly of the landing gear door. The landing gear door and wing structure are evenly distributed with insulation board and heat insulation tile, and hydraulic pipe is arranged. When the space shuttle flies out of the atmosphere, the insulation board falls off. If the insulation tile on the side of the door is damaged, the air tightness of the door will fail. There is external gas flowing into the landing gear cabin, and the hydraulic pipe here is also exposed to the high temperature airflow. At the same time, the mechanism structure, hydraulic system and cable in the landing gear cabin are in a dangerous working environment, and the safety and reliability are greatly threatened. Since then, American space shuttle experts have carried out research on the airtight performance of landing gear doors. The traditional door sealing structure is mainly composed of hollow tubular sealing strip of silicone rubber, which is different from the traditional structure. In the later stage, by strengthening the door sealing structure and using new materials such as ceramic fiber, the rebound performance of the sealing structure of the space shuttle in high temperature environment is improved, and the air tightness reliability under special flight conditions is guaranteed.

2.5 Pipes and joints of aircraft constructions and so on

2.5.1 Introduction to aviation fittings

Aviation fittings can be generally divided into three categories: permanent fittings, separable fittings, and boss fittings. [22-23] Permanent fittings are a type of permanently connected, non-detachable pipe joints with strong pressure resistance and reliability, light weight and volume, and are widely used in aircraft hydraulic systems. separable fittings are a kind of pipe joint that can be disassembled and maintained. They have good maintainability, but their quality and volume are relatively large, the number of joint parts is large, and their reliability is average. Boss fittings are usually located at the end of the pipeline system and require high mechanical connection strength. Other types of pipe joints are generally only for specific occasions.

As far as the current development trend in aviation fittings, some fittings have become the mainstream because of their high reliability, simple assembly process and other advantages. There are shape-memory couplers in the permanent fittings, flareless fittings in the separable fittings, O-Ring Boss Fittings in the boss fittings. With the development of aviation fittings, they are developing in the direction of high pressure and lightweight and using composite materials.

In the past, China did not pay enough attention to the research of aviation hydraulic fittings, which led to the consequence of lagging far behind developed countries in this field. The main products occupy the mainstream position of my country's military aircraft, which are at the level of the 1970s. [21] Manufacturers are mainly domestic military aviation manufacturers, and the production cost is low. Compared with foreign advanced aviation connectors, the pressure resistance level is low and the reliability is poor. In the field of civil aircraft, the performance and standards of traditional domestic aviation pipe joints are backward, and it is difficult to meet the requirements of international civil aviation airworthiness certification.

The hydraulic pipe fittings used in China's self-developed civil aircraft ARJ21 and C919 can only be imported from the mature products and supporting assembly equipment of companies such as Eaton, Parker, and Aerofit in the United States.

2.5.2 The introduction to aviation pipes

Aviation hydraulic pipes are an important method for the transmission of mechanical energy. It should have good sealing, temperature resistance, vibration resistance, fatigue resistance, corrosion resistance, manufacturability, maintainability, and reliability. If there are defects in design and processing, improper operation in the process of installation, use and maintenance may cause damage and cracking of the conduit and even cause the hydraulic system to fail, causing the aircraft to lose control and cause an accident.

Hydraulic pipes have the following characteristics: [24]

1. The pipes are long and the pipes have thin walls and many bends, which are more likely to wear.
2. The working condition is relatively bad. They are subjected to hydraulic pressure (including hydraulic pulsation and hydraulic shock). They are subjected to alternating vibration loads generated by vibration sources such as aero engines, turbine starters, and hydraulic pumps. They are subjected to aerodynamic loads during flight, maneuvering overloads, and shock loads when the aircraft lands (or lands). They withstand the compressive and tensile stresses generated by the conduit during processing and assembly.
3. These pipes are installed on the body. Due to the low rigidity of the support

body, it is easily affected by impact, resonance, and body deformation.

4. These pipes are easily affected by environmental factors such as ambient temperature, humidity, salt spray, and corrosion.

Rupture is the most serious form of pipe damage, which is easy to cause hydraulic oil leakage and fire. There are the most common causes which lead to rupture, including wear, corrosion and fatigue. Usually, they are caused by the solid-liquid coupling vibration of the hydraulic pipes. Under the various combined loads, the surface of the pipes is often damaged in some areas, including the exposed area of the aircraft (such as the landing gear cabin and the landing gear pillar), the strong vibration area (such as the engine cabin, the aircraft attached casing cabin, the weapon cabin) and other parts of the duct surface integrity, such as the end of the duct. Microcracks initiate and propagate further under alternating loads, causing fatigue damage.

2.5.3 Some related accidents to the pipes

Here are some serious accidents caused by this kind of component. On 30 July 2007, a Boeing 777-200 passenger plane carrying 264 passengers and 13 crew members flew from Ho Chi Minh City, Vietnam, to Narita Airport, Tokyo, Japan. According to Narita Airport's Tata air traffic controllers, during the landing process, the right engine suddenly smoked, the plane slid to the boarding gate, and passengers normally disembarked. About an hour after the plane landed, the right (smoke) engine began to burst into flames but was quickly extinguished by fire crews. On April 23, 2012, the Japan Transportation Safety Board (JTSB) released the final investigation report of this incident. It is believed that the possible reason is that during the taxiing process after landing, the fuel hose of the right engine began to leak and cause a fire. Leakage is caused by a crack caused by an O-ring (slightly smaller than required) which is installed without lubricant.

On 23 August 2001, an A-330 flew from Toronto Pearson International Airport to Lisbon. After a 5h20min flight, the fuel imbalance alarm. The driver opens the fuel exchange valve. Due to abnormal fuel consumption, the right and left side of the aircraft engine has been due to fuel depletion and stopped working. The pilot controlled the aircraft to taxi for 25 minutes and then made a forced landing at Lajes Air Force Base on the island of Tesla in the Daraya Islands. On the right side of the engine maintenance process, using different types of old parts, resulting in the engine hydraulic pipe and tubing friction, tubing fracture, and engine oil leakage. The alarm system failed to alarm. The driver needed to correctly determine the leakage and fuel imbalance, resulting in fuel consumption.

An Airbus A321-200 flight from Saipan to Osaka Kansai on January 16, 2010, carrying 51 passengers and 8 crew members. When cruising at FL370 altitude about 300 n miles south of Osaka, the aircraft lost pressure in the cabin and urgently dropped to 10,000 ft. The plane continued to Osaka Kansai Airport and landed safely 70 minutes later. No one was injured. Hot air leaks from the duct connecting the right side valve assembly to the main heat exchanger. A seal strip was found inside the duct to be flattened and damaged, pending an airworthiness directive; the sealing strip was not replaced, and the replacement work was delayed. The detection rings on both sides are normal. Due to structural problems, both detection rings detected hot air flow and automatically shut down the air conditioning system.

2.5.4 The electricity lines in aviation

With the development of modern science and aviation technology, the electrical equipment on aircraft is increasing, and the quantity and quality of electricity are improving, which puts forward stricter requirements on the reliability, maintainability, and testability of the aircraft electrical system.

The wire for civil aviation tests and maintenance is the fundamental component of the aircraft transmission and distribution system. It is twisted together by multiple strands of copper wire or silver-plated copper wire or aluminum wire in an insulating layer. It is an important device for connecting lines and transmitting power sources between various aircraft electrical equipment. It is widely distributed in various parts of the aircraft. It has a large amount, many types, wide applications and a complex working environment. From the cockpit to the tail, the amount of aircraft wires is considerable. For example, all the wires of the Boeing 737 aircraft are connected, with a total length of 280 km. The mass of the DC-10 aircraft wire is 60 % of the total mass of the airborne electronic equipment and electrical equipment, and the total mass of the Concorde aircraft wire is 1500 kg. Due to the structure of the aircraft's structure, the volume and weight of the wire are limited, and the installation space of the wire is very narrow. Most of the wires are arranged in bundles between various airborne electrical equipment or the aircraft's wall according to the category. The wire works in an environment of vibration, pollution, friction, external force, cold, heat, humidity, and radiation for a long time, which makes the wire prone to failure, resulting in power supply interruption, indicating instrument instability, control machinery does not work, the signal is not normal, wire short circuit causes fire and other consequences, which seriously endangers the flight safety of the aircraft and has caused many flight accidents. The problem of aircraft wire fault diagnosis and location has become one of the urgent problems in international civil aviation.

The inevitability of aircraft wire fault

Causes of aircraft wire failure can be divided into the following five categories:

1) Contact pollution refers to the fact that the insulation layer of the wire is oxidized or corroded due to the poor environment in which the aircraft wire is in contact with pollutants such as hydraulic oil, lubricating oil, grease, anti-icing agent, detergent, water, toilet or kitchen waste for a long time, resulting in reduced performance of the aircraft wire.

2) physical damage refers to the aircraft wire contact with metal objects, friction with the surrounding objects, unreasonable binding or laying, artificial stretching or stampede, subjected to vibration stress and other physical processes, the wire wear or fracture, contact loose or damaged, resulting in aircraft wire performance degradation.

3) Time aging means that due to the long-term use of the aircraft, the physical and chemical properties of the metal and non-metallic materials of the wire change with time in hot and humid environments. The material decomposes and volatilizes so that it changes in elasticity, strength, flexibility, compressibility, bending, conductivity, moisture resistance and other aspects, resulting in a decrease in the performance of the aircraft wire.

4) Environmental impact means that due to geographical and meteorological reasons, the aircraft wire is affected by high temperature, cold, humidity, high altitude ray particle radiation, and other factors, so the long polymer chain of the insulation layer of the aircraft wire is broken, resulting in small cracks in the insulation layer, resulting in reduced performance of the aircraft wire.

5) improper assembly and maintenance refer to the aircraft wire in the assembly and maintenance process, improper construction of wire tension is too large, excessive bending, peeling size is too large, and cutting size is too deep, resulting in aircraft wire performance degradation.

2.5.5 Some accidents caused by the lines in the aircrafts

On 17 July 1996, shortly after takeoff from New York's John F. Kennedy Airport, the Boeing 747 TWA800 of Universal Airlines exploded in a fuel tank on the central wing after a short-circuit spark from a wire, sending the plane crashing into the Atlantic Ocean off Long Island, killing all 230 people on board.

On September 2, 1998, the MD-11 aircraft of Swiss Airlines flight number SR111 took off from New York for more than an hour. Due to the short circuit of the cabin entertainment system, the cockpit of the aircraft caught fire, which caused the aircraft's electronic, communication, and control system to stop working, causing the aircraft to fall into the Atlantic near Canada, resulting in the death of 229 people on board.

On April 25,2001, Canadian Airlines Flight 797 DC-9 took off from Dallas, the United States, one and a half hours later. Due to the short circuit of the tail bathroom wire, the cabin caught fire and 23 passengers died.

In 2002, China Southern Airlines Shenzhen maintenance factory management of 10 A320 aircraft due to repeated wire failure, resulting in aircraft repairs as many as ten times, resulting in flight delays or cancellations, affecting the normal operation of the airline.

2.6 Conclusion

Tightness control is of great importance for many components in aircraft maintenance and operation. In this chapter, we discuss several types of aircraft structures and systems with tightness control, which include:

1) The fuel tanks of the plane
2) The rivet joints of the fuselage
3) The hydraulic systems of the aircraft chassis
4) Fuselage and some relevant components
5) aviation fittings
6) aviation pipes
7) The electricity lines

Some factors connected to tightness control are discussed, which can lead to failures and even accidents. Then factors are analyzed for further discussion on them. At last, some actual accidents connected to them are included to prove the damage without tightness control.

3. Development and testing of the technology of control of the tightness of aircraft structures using the method of penetrating substances on samples

3.1 The introduction to the capillary method

Now for leak testing of unclosed constructions, the capillary method is applied as a rule. This non-destructive testing method by liquid penetrant is one of the oldest and most widely used testing methods for responsible technical objects. It is enough to mention a well-known kerosene-chalk method.

Generally, air-leakage detection for the unclosed components is always carried out in the final assembly of aircraft. [25] At the same time, unclosed construction refers to aircraft elements that cannot be pressurized utilizing a test medium. [26]

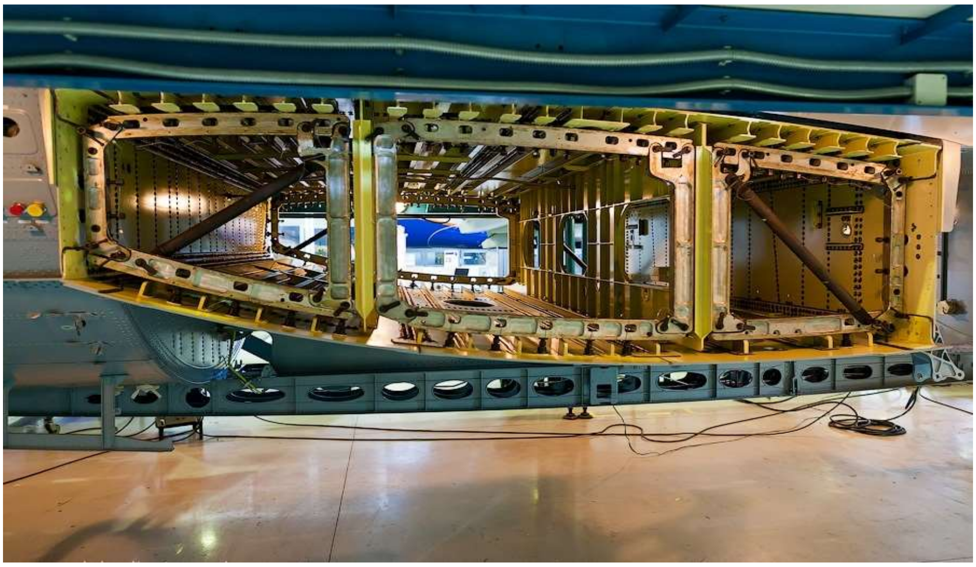


Fig. 4 Example of unclosed aircraft construction

3.1.1 The physical base of the capillary method

The root of CDM () is the phenomenon of capillary action, which is the phenomenon of liquid ' wetting ' the solid surface due to the adhesion force on the liquid-solid interface. In liquid penetrant testing, the good wetting characteristics of a liquid penetrant are conducive to its flow into surface holes and cracks, which is conducive to the detection of defects.

The "contact angle" between the liquid surface and the solid surface is used to gauge the wetting capacity (Fig.2). A reduced contact angle and a more vital ability to draw in and fill surface gaps are two benefits of the liquid's good wetting characteristics. Also, the surface tension of the liquid is related to the wetting ability.

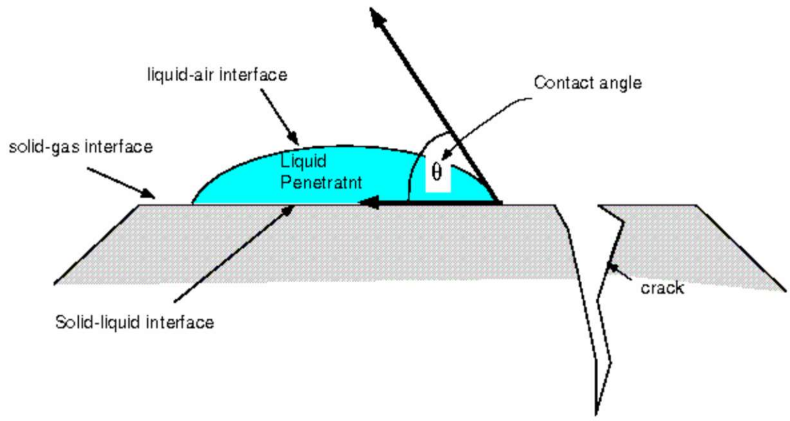


Figure 5. The contact angle between a liquid penetrant a solid surface. [27]

In CDM, the liquid penetrant is driven to fill the surface spaces by the driving pressure, also called "capillary pressure." Surface tension and fracture width are inversely correlated with the pressure. The contact angle and depth of liquid penetration are directly correlated with the pressure. Until the driving pressure is balanced by the opposite pressure, the penetrant will continue filling the voids. And during the filling of the blind conical capillary with a liquid, the air gets into the capillary and accumulates at the capillary top. Air is slowly dissolved in most liquids. Therefore so-called diffusive impregnation is long. [27] At this time, the maximum penetration depth is reached. The excess penetrant on the surface must then have a brief period to dissipate. It costs several seconds to finish the exposure time.

The CDM indicator consists of chemically treated special sheets that react in a gaseous form with molecules diffused from the defect and is designed to provide a color impression of the surface defect. Figure 3 depicts this process. The indicators used in CDM technology are completely safe and easily obtain a moderate price.

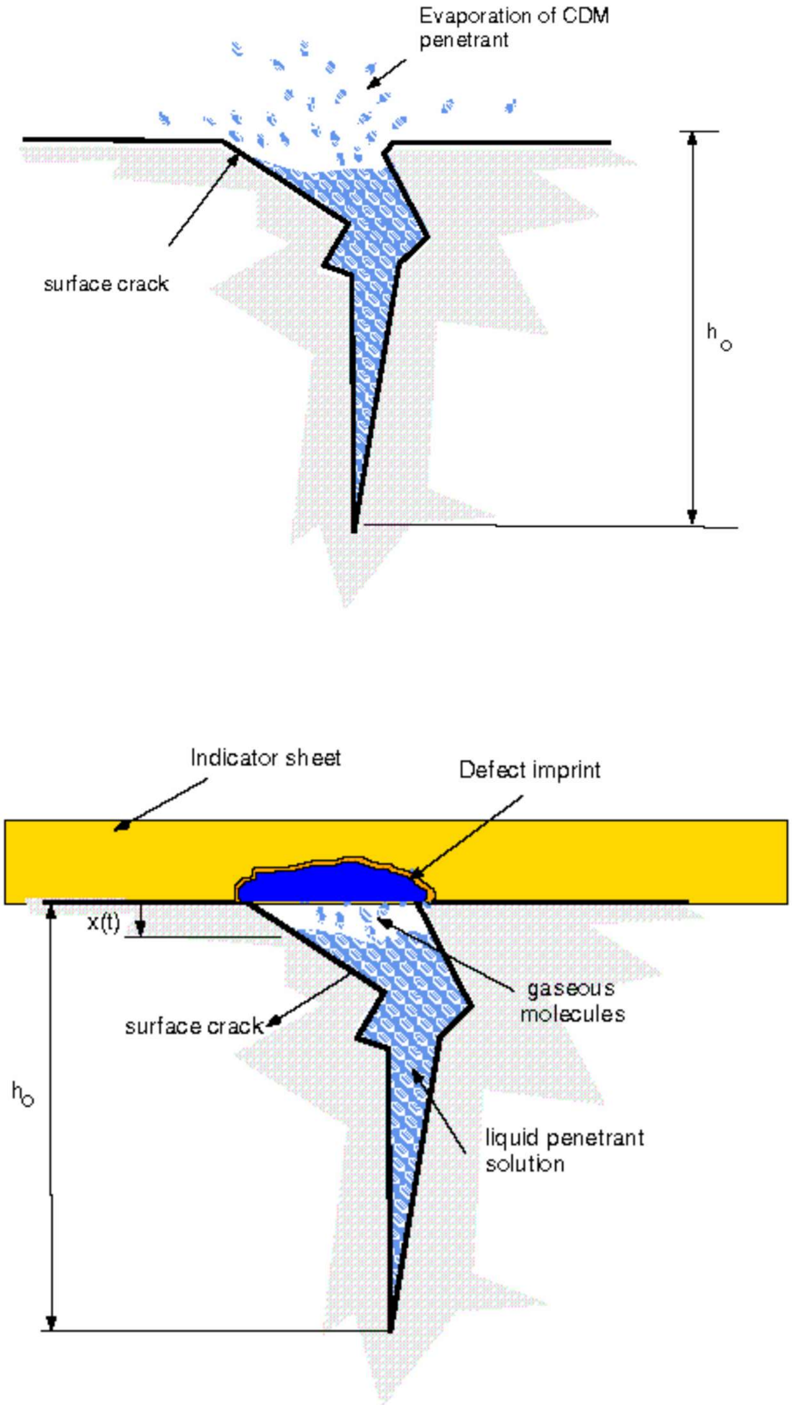


Figure 6. CDM defect detection process. [28]

The key characteristic of the CDM test is the diffusion flux rate of the evaporating penetrant out of the flaw, and into the indicator. The solution concentration of the penetrant is volatile by design, and its purpose is twofold, (a) to furnish information about the presence and depth of defects by reacting with the indicator, and (b) to vanish from the flaws and make the postcleaning unnecessary. [28]

3.1.2 The procedure of the capillary method

According to the standard [30], the whole processing operation can be divided into nine parts: 1. Surface Preparation 2. Penetrant Application 3. Penetrant Removal 4. Drying 5. Developing 6. Inspection 7. Post cleaning 8. Quality Control Provisions 9. Marking and Identification

The procedure of the operation can be described in the figure 7 below: [29]

The advantage of a liquid penetrant inspection over an unaided visual inspection is that it facilitates the inspector's ability to detect faults in two ways:

1. It creates a defect indicator that is much larger and more visible than the original flaw. Many defects are much too minute or narrow to be seen with the naked eye. The naked eye cannot tell the differences smaller than 0.08 mm.

2. The high level of contrast between the indicator and the background makes the indication easier to detect, which improves the detectability of a defect.

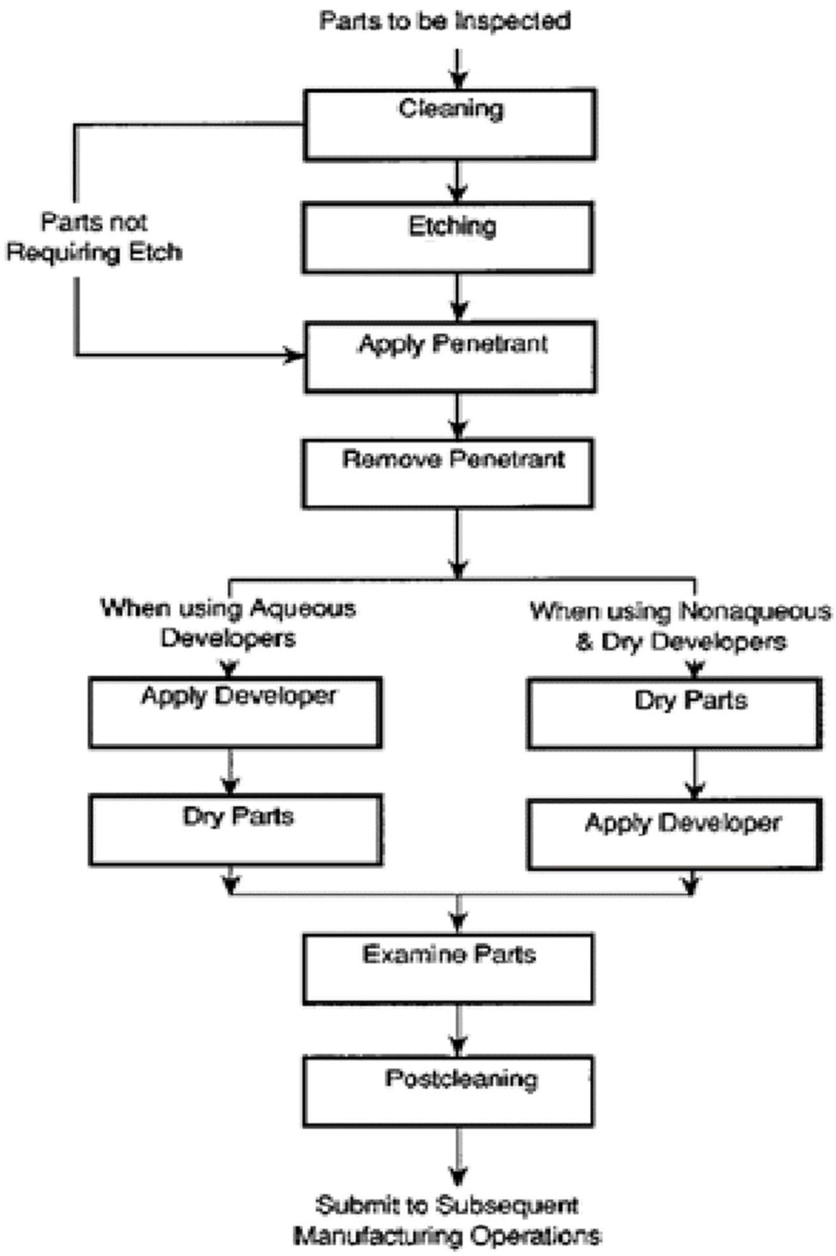


Figure. 7 Process Flow Chart

3.1.3 The practical penetrants testing

We have improved the sensitivity of penetrant testing through the use of our unique harmless dye ("the basic raspberry"), synthesized from medicinal raw materials.

Penetrants on its basis are environment-friendly, fireproof, and flameproof. Figure 8 shows dye “traces” of defects on the test surface of the fuel tank. The surface of casting was checked by the dye capillary method.

Fig. 8 Dye “traces” of defects on the test surface of the fuel tank

3.2 Detecting defects caused by impacts on the surface of aircraft structures

3.2.1 The introduction to the bird strike

The bird strike is a major threat to both civil and military aircraft. The first bird strike dates back to September 7, 1905, recorded by the Wright brothers. [30] The United States Air Force reported 13427 bird/wildlife strikes to aircraft worldwide between 1989 and 1993 and estimated the damage to civilian and military aircraft to cost hundreds of millions of dollars every year. [31] Takeoff and landing was the most common part of a flight for bird strikes to occur in airplanes, while helicopters sustained strikes mostly while parked on the ground, or during cruise and approach to land. [32] So it makes the bird strike more dangerous and more significant.

Phase of flight	Number of birdstrikes
Taxiing	101
Takeoff	4,442
Initial climb	708
Climb	75
Cruise	88
Maneuvering/airwork	47
Descent	76
Approach	1,763
Landing	3,083
Unknown[8]	2,064
Total	**12,447**

Tabel.3 Number of bird strikes by phase of flight for airplanes in Australia, 2002 to 2011 [32]

And although many methods are done in advance, there is still impossible to prevent this case. In one study, the authors assessed whether aircraft lighting might enhance the detection of and reaction to the approach of an aircraft by Canada geese [33], a species that causes a disproportionate degree of damage to US civil aircraft. [34] In another study, the authors used a numerical method to design bird-strike-resistant aircraft structures presented and illustrated through examples. [35]

The collision between aircraft and birds, and the impact of ground cover debris during take-off or landing of aircraft will lead to structural damage and strength reduction of aircraft, especially components made of composite materials. The most vulnerable part of the structure subjected to bird strikes is the wing, especially the components of the flight control system. So there is a need to have a method to detect and evaluate the damage of bird strikes. Otherwise, it not only increases the operating cost of aircraft but also reduces the efficiency of the airport.

3.2.2 Some models of fast detection for the bird strike

Here is a specialized paint coating that allows you to diagnose bird or gravel impact sites quickly, i.e., damage to the aircraft's outer surface. Its implementation includes the deformation and destruction of a special indicator composition due to a mechanical impact (Fig. 9). The luminophore reaches the damaged surface and is observed in UV light.

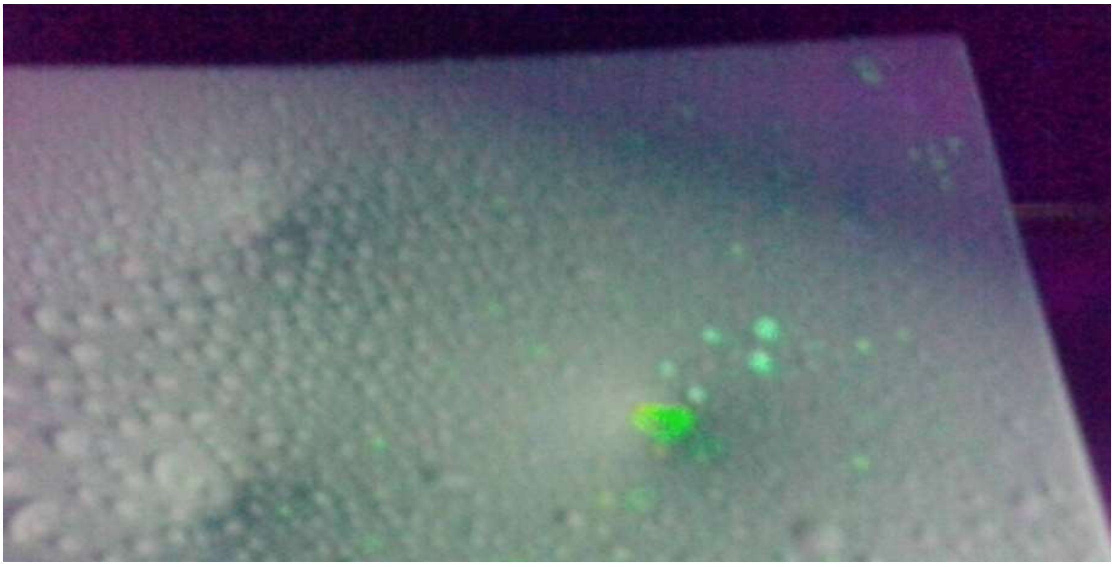


Fig. 9

Here are three methods of detecting defects by capillary luminescence control are proposed:

1. Modification of the luminescent capillary control, namely: the introduction of penetrant ЛЖ-6АМ (ТУ У 21585720-049-99) with phosphor 490RT yellow-green in the amount of 1.0% by mass into the standard paint.

2. Preparation of emulsion paint with microcapsules 5-10 μm in size based on regular polyurethane coating using ethylene glycol phosphor solution.

3. Introduction of fluorescein phosphor particles with a size of 1-3 μm into standard polyurethane paint. Before the control, the surface of the structure is moistened. Thanks to the phosphor solution, defects from impacts are observed in the damaged areas.

Method No. 1

after an impact with an impact energy of 6.7 joules, due to mechanical damage in the outer coating, the penultimate layer can be seen glowing in UV light.

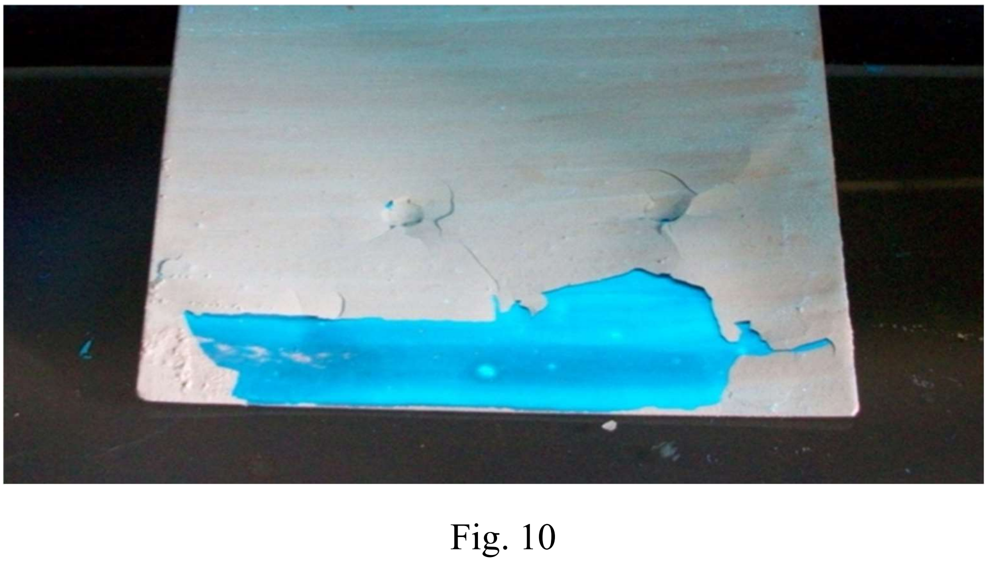


Fig. 10

Method No. 2

Drops of phosphor solution in ethylene glycol. Image of a sample made by method 2 after impact.

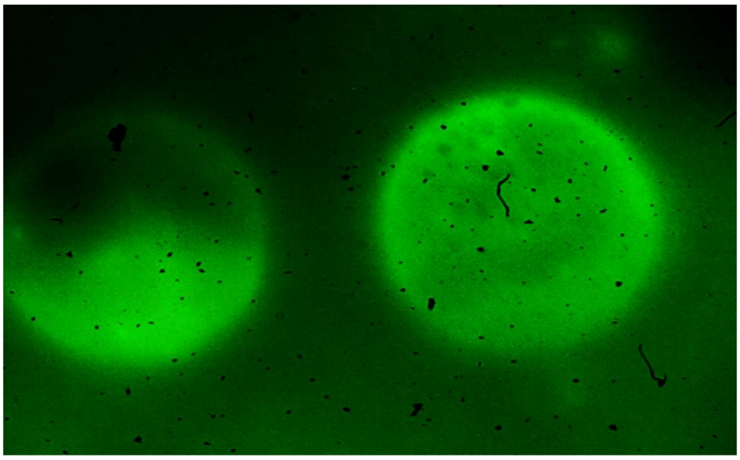


Fig. 11

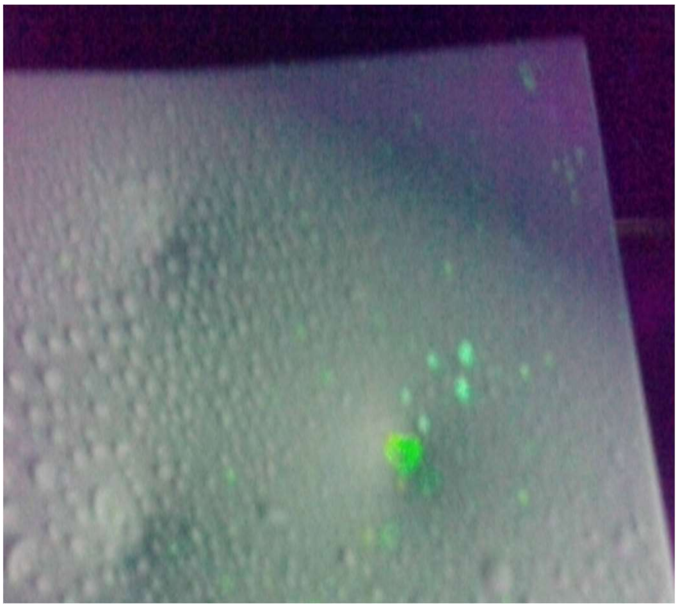


Fig. 12

Method No. 3.

Before control, the surface is moistened with water. Penetrating into defects, water dissolves "fluorescein", which diffuses to the outer surface of the part and becomes visible when illuminated by a source of UV radiation. Image of the sample prepared according to method 3, after impact.

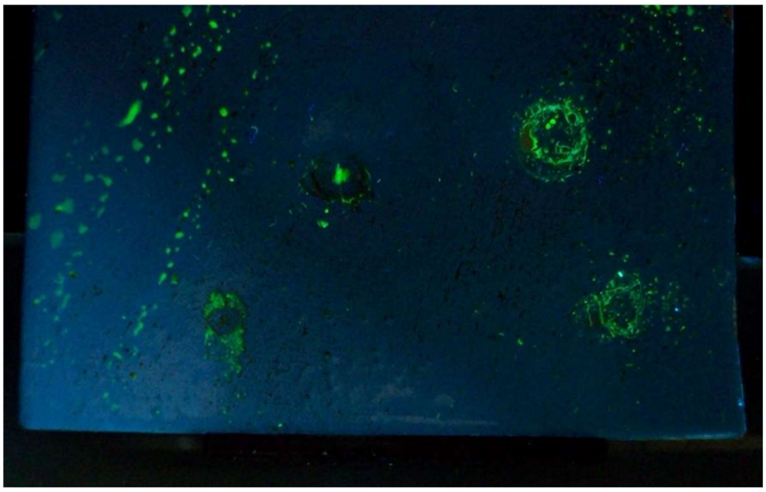


Fig. 13

3.3 Conclusion

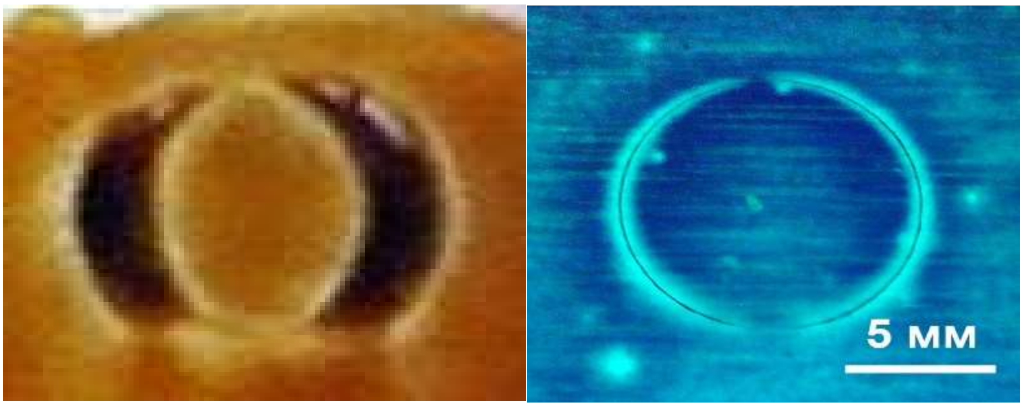
This chapter first introduces the capillary method and shows the importance of this method. Then the physical base of the capillary method shows the principle of this method and indicates the use of it. Also, the procedure and some practical test cases of this method are introduced.

In the next part, the damage of the bird strike shows the frequency of this kind of accidents. Then some models connected to bird strike are shown to show the advantages of this method, which is operated easily and fast.

4. Development and testing of the technology of combined methods of air tightness control using capillary and magnetic methods

4.1 The introduction to the combined capillary and magnetic methods

This promising method uses magnetic fluid in magnetic diagnostics of aircraft structures to improve the tightness control for the aircraft, which combines the capillary and magnetic methods. The common magnetic method cannot visualize the detection right after the testing. When compared to the common capillary method, it is impossible for the common one to detect the track below the surface 3 mm. When these two methods are combined, it shows that the use of magnetic-luminescent liquids in the magnetic method of non-destructive testing is characterized by high sensitivity. Magnetic fluids are sedimentation-stable colloidal solutions of magnetic particles with nano dimensions, the distinguishing feature of which is that the entire volume of the solution is drawn into the applied magnetic field [36,37]. The combination of fluidity and a high value of magnetization allows the use of magnetization in various fields of modern technology. Due to the use of $CoFe_2O_4$ nanoparticles with sizes from 5 to 30 nm, the complex method makes it possible to detect smaller defects and reveal the fine structure of indicator «traces» in products made of ferro- magnetic materials. Varying the magnetization conditions and control technology makes it possible to obtain different configurations of the fine structure of the indicator «trace» of the same defect, which contains information about the behavior of the penetrant in the presence of a magnetic field.



A B

Fig. 14 Visualization of the defect: a – using a magnetic liquid, b –using a magnetic luminescent composition

The combined use of capillary and magnet luminescent methods makes it possible to control defects in nonmagnetic materials with using of the magnetic fluids and increases the sensitivity of the simple capillary method. It is known that the magnetic particle inspection method is used for non-destructive testing in aviation only for ferromagnetic parts. And the applicator of the proposed method expands the possibilities of testing non-magnetic structures with high sensitivity. Invention of these technologies in aviation is developed.

4.2 The advantages of the combined capillary and magnetic methods

The advantages of this method can be concluded into:

1. The material is cheap and easy to produce
2. Chemical stability
3. Aggregation and settling resistance
4. High sensitivity
5. Easy to visualize the defects

The use of nanoscale particles, especially in combination with luminescent dyes, will allow to increase the sensitivity of materials obtained based on them compared to materials based on micron-scale magnetic particles. According to the results of the work, a magnetic fluid was developed based on CoFe2O4 nanoparticles with an average size of 8 nm (according to TEM (transmission electron microscopy) data) [38]. Nanoparticles are formed during the thermal decomposition of the heterometallic complex [Fe2CoO(CH3COO)6(H2O)3]·2H2O using tetraethylene glycol as a solvent and oleic acid, which acts as a surfactant that limits crystal growth. As well as the creation of magnetic particle compositions using polymers will allow obtaining a replica of the defect visualization results immediately after the defect inspection procedure itself, without the need for additional procedures and materials.

When using such a liquid, the defect (a crack with an opening width of 1.2 μm) appears as a wide black band (accumulation of magnetic fluid), which is surrounded on both sides by bands with the smallest amount of magnetic fluid. According to the classification according to ГОСТ, the magnetic fluid belongs to the highest conventional level of sensitivity – A [39]. It is shown that the use of a magnetic liquid in the method of magnetic powder flaw detection makes it possible to detect defects parallel (for the arc region) to the magnetic field, which cannot be realized using a magnetic suspension.

The analysis can conclude that the amount of fluid has no effect on image quality. [40] Therefore, the strength of the magnetic field and the amount of liquid in the study range have no significant effect on the contrast of the image, simplifying the process of detecting defects.

4.3 The operation procedures

Replicas were made in three ways:

Method 1. Use of magnetic fluid with dissolved polymer.

The composition was applied to the surface of the sample, the sample was magnetized, dried, and then the formed film with the image of the defect was removed.

Method 2. Using the composition of a magnetic liquid with a monomer followed by polymerization on the defect.

The composition was applied to the surface of the sample, the sample was magnetized, an oxidant was applied with a sprayer, after polymerization it was dried, then the formed film with the image of the defect was removed.

Method 3. Applying the polymer to the surface of the sample before flaw detection.

A solution of a water-insoluble polymer was applied to the surface of the sample, dried, an aqueous magnetic liquid or composition was applied to the resulting film, the sample was magnetized, dried, then the polymer film was peeled off together with the image of the defect.

The compositions studied in this work were evaluated according to the following criteria:

- sensitivity of defectoscopy;
- replica quality;
- complexity of the process.

At the preliminary stage of work in the study of magnetic fluid, the influence of such conditions of flaw detection as the concentration of magnetic fluid was established, the strength of the magnetic field, and the amount of magnetic fluid. It was established that the intensity of the magnetic field in the range of 11-19 kA/m has no significant effect on the image contrast, the optimal consumption is 82 ml/m2, the concentration significantly affects the image contrast, the optimal concentration is 1.6 g/l. It was with this concentration of nanoparticles that compositions were used in the third stage of work.

The optimal polymer concentration was selected for each composition. At low concentrations, a thin, inconvenient film that stretches and tears easily is obtained. At high values, it is a viscous solution that reduces the sensitivity of flaw detection.

The composition of a magnetic liquid with polyethylene oxide at a polymer concentration of 0.5% is characterized by high sensitivity in flaw detection. After drying the composition, the layer formed on the defect fully reflects the defect, is strong, the magnetic particles are fixed in the polymer matrix and do not fall off. In this way, the composition can be used to fix the results of defectoscopy. However, the composition cannot be used to remove the replica due to the high fragility of the formed polymer layer and the difficulty in obtaining a complete replica.

The optimal polymer concentration when using a composition with polyvinyl alcohol is 2%. Polyvinyl alcohol slowly dissolves in water, so it becomes impossible to prepare a composition from the concentrate immediately before use. The specified composition is characterized by high sensitivity in flaw detection. Replicas are obtained by peeling off the dried composition from the surface. The replica is characterized by high quality, elastic, fully reflects the pattern of the defect.

When carrying out flaw detection with a composition based on polyvinyl acetate, the optimal concentration of the polymer is 5%. The image of the defect is formed on the white background of the polymer (Figure 15), which increases the contrast of the image. This feature of the composition with polyvinyl acetate can be explained by the formation of suspensions with relatively large polymer particles that are not drawn into the defect zone together with the solvent. It should also be noted that polyvinyl acetate contributes to the aggregation of magnetic nanoparticles, as a result of which the image on the replica is characterized by a large "graininess", but this does not reduce the sensitivity of the method (Figure 16).

Fig. 15 - Formation of an image of a defect by composition with polyvinyl acetate.

Fig. 16 - Replica formed by composition with polyvinyl acetate.

The composition with carboxymethyl cellulose at a polymer concentration of 0.5% is characterized by high viscosity. The pattern of the defect is low contrast, which can be explained by the small volume of the composition, which is concentrated in the area of the defect's scattering magnetic fields due to the high viscosity of the material. Due to the high adhesion to the steel sample, it takes a long time to get a complete replica. The resulting replica is elastic. Taking into account the sensitivity of defectoscopy and the complexity of the process of obtaining a replica, the composition with carboxymethyl cellulose is inferior in its characteristics to other developed compositions.

When testing the composition with gelatin, the polymer concentration of 2.5% turned out to be optimal. In order to reduce the viscosity of the solution and increase the sensitivity, it was proposed to conduct defectoscopy using a hot material. Replicas are strong, elastic, fully reflect the pattern of the defect, and are obtained quickly and easily.

Figure 2.5 shows a replica obtained by the third method using water-insoluble fluorovinyl-fluoropropylene copolymer (3%) and aqueous CM (Composite material). The replica is elastic, does not tear, does not stretch, does not break, particles do not fall off.

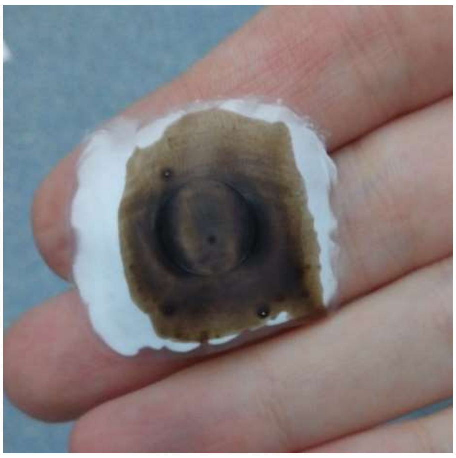


Fig. 17 - Replica obtained using fluorovinyl-fluoropropylene copolymer.

When using CM with a low concentration of particles (0.8 g/l), a wide band of magnetic fluid formed over the defect splits into three parts when drying (Figure 2.6). The middle band is formed by magnetic particles drawn into the defect field. Two side bands are formed due to the self-organization of nanoparticles in a colloidal solution, the so-called "coffee drop phenomenon" [41, 42]. Perhaps such a feature will allow to distinguish a defect from an artifact or an error in the technology of defectoscopy, which requires further research.

Fig. 18 - Defect image obtained by method 3, using fluorovinyl-fluoropropylene copolymer and CM with a concentration of 0.8 g/l.

Advantages and disadvantages were highlighted for each composition, which are summarized in Table 4.

Polymer	Advantages	Disadvantages
Fluorovinyl-fluoropropylene copolymer	form an elastic film	insoluble in water
Polyethylene oxide	form a strong layer	fragile
Polyvinyl alcohol	forms an elastic film	sparingly soluble

Polyvinyl acetate	forms an elastic film	destabilizes CM
Carboxymethylcellulose	forms an elastic film	forms viscous solutions causing low sensitivity
Gelatin	forms an elastic film	the need to work with hot solutions

Table. 4

4.4 Conclusion

In this chapter, the introduction to the combined capillary and magnetic methods indicates the use and the principles of this method and shows the visualization of the defect. Then the advantages are discussed to indicate the superiority of this method. Finally, the operation of this method shows the procedure for detection and manufacture. Replicas were made in three ways:

Method 1. Use of magnetic fluid with dissolved polymer.

Method 2. Using the composition of a magnetic liquid with a monomer followed by polymerization on the defect.

Method 3. Applying the polymer to the surface of the sample before flaw detection.

The advantages and disadvantages of each method are compared with table.

5. Development and manufacture of the design of a portable ultrasonic leak detector and its experimental verification

5.1 The basic principle

5.1.1 The generation of the ultrasound

The sound waves are generated under differential pressure when the air flows out of the cabin or any part else. In this case, several vortices form turbulence when the air comes out at high speed due to the considerable differential pressure. According to the analysis in the article *Research and Design on a Portable Intravehicular Ultrasonic Leak Detector for Manned Spacecraft* [43], the air from a vacuum cabin has a center frequency connecting to the leak diameter is shown below in the table.

CENTER FREQUENCY OF DIFFERENT DIAMETER OF LEAK SIGNAL

Leak diameter (mm)	0.3	0.4	0.8	1.0	1.5	2.0
Center frequency (kHz)	196.7	147.5	73.8	59.0	39.3	29.5

Table. 5

Leakage greater than 2mm can be easily found with the naked eye. At the same time, the leakage is large and can generate a relatively loud sound of less than 20kHz. The operator can easily find it with hearing and naked eyes. So we only need to concentrate on the detection of ultrasound.

5.1.2 The reason for choosing the 40 kHz frequency

The ultrasonic sensor is based on the principle of the piezoelectric effect. The piezoelectric effect has an inverse effect and a cis effect. The ultrasonic sensor is a reversible element, and the ultrasonic transmitter is based on the principle of the piezoelectric inverse effect. The so-called piezoelectric inverse is the applied voltage on the piezoelectric element. The element deformation is called strain. The external positive charge is repulsive to the polarized positive charge of the piezoelectric ceramic, and the external negative charge is repulsive to the polarized negative charge. Due to the repulsion, the piezoelectric ceramic is shortened in the thickness direction and elongated in the length direction. If the polarity applied externally becomes reversed, the piezoelectric ceramic elongates in the thickness direction and shortens in the length direction.

The ultrasonic sensor adopts a double-crystal oscillator. That is, the double piezoelectric ceramic sheets are bonded together in the opposite polarization direction. In the length direction, one piece is elongated, and the other is shortened. The two sides of the double-crystal oscillator are coated with a thin film electrode. A lead is connected to an electric pole through a metal plate (vibrating plate), and the lead is directly connected to another electric pole. The double crystal oscillator is square, and the convex arc part supports the left and right sides. These two fulcrums become the nodes of oscillator vibration. The center of the metal plate has a conical vibrator.

When sending ultrasonic waves, the conical vibrator has strong directivity, so it can send them efficiently. When receiving the ultrasonic waves, ultrasonic vibration is concentrated in the center of the oscillator to produce high-efficiency, high-frequency voltage. Suppose a high-frequency voltage of 40kHz is applied to the double crystal oscillator of the transmitter (resonant frequency of 40kHz). In that case, the piezoelectric ceramic sheet will elongate and shorten according to the polarity of the high-frequency voltage so that the ultrasonic wave of 40kHz can be transmitted. The ultrasonic wave propagates in a dense wave and is transmitted to an ultrasonic receiver. The ultrasonic receiver is based on the piezoelectric effect principle. By applying pressure in a specific direction of the piezoelectric element, the element will strain, and the voltage of one side will be positive, and the other side will be negative. If the ultrasonic wave sent by the transmitter is received, the oscillator vibrates at the frequency of the transmitted ultrasonic wave. Therefore, a high-frequency voltage with the same frequency as the ultrasonic wave is generated. Of course, this voltage is tiny and must be amplified by an amplifier.

Here we can take the actual sensor HX40TR [44] as an example, which includes the characteristics of frequency and directionality.

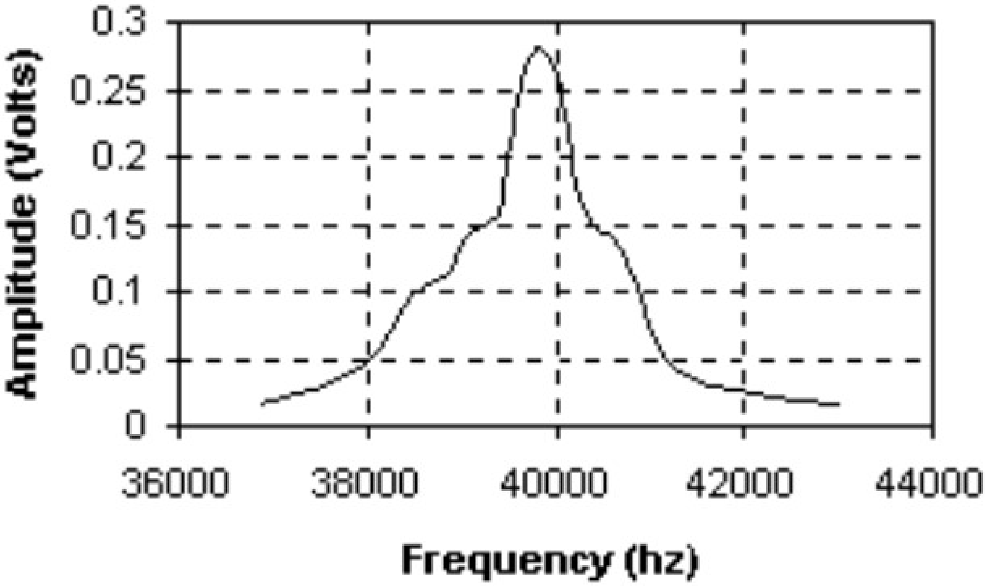


Fig. 19 Frequency Characteristics of Ultrasonic Sensor

In the picture is the frequency characteristic curve of the ultrasonic emission sensor. Among them, f_0 = 40kHz is the center frequency of the ultrasonic emission sensor. At f_0, the ultrasonic emission sensor's ultrasonic mechanical wave is the strongest; that is, the ultrasonic sound pressure level generated at f_0 is the highest. On both sides of f_0, the sound pressure level decays rapidly. Therefore, the ultrasonic emission sensor must be excited using an AC voltage close to the center frequency f_0. In addition, the frequency characteristics of the ultrasonic receiving sensor are similar to those of the ultrasonic transmitting sensor. The curve is the sharpest at f0, and the amplitude of the output signal is the largest; that is, the receiving sensitivity is the highest at f0. Therefore, the ultrasonic receiving sensor has good frequency selection characteristics. The frequency characteristic curve of the ultrasonic receiving sensor is also related to the external resistance R of the output end. If R is large, the frequency characteristic is sharp resonance, and the sensitivity is very high at this resonance frequency. If R is small, the frequency characteristics become smoother with a wider bandwidth, and the sensitivity decreases. And the maximum sensitivity moves to a slightly lower frequency. Therefore, the ultrasonic receiving sensor should be used with the preamplifier with high input impedance to have higher receiving sensitivity.

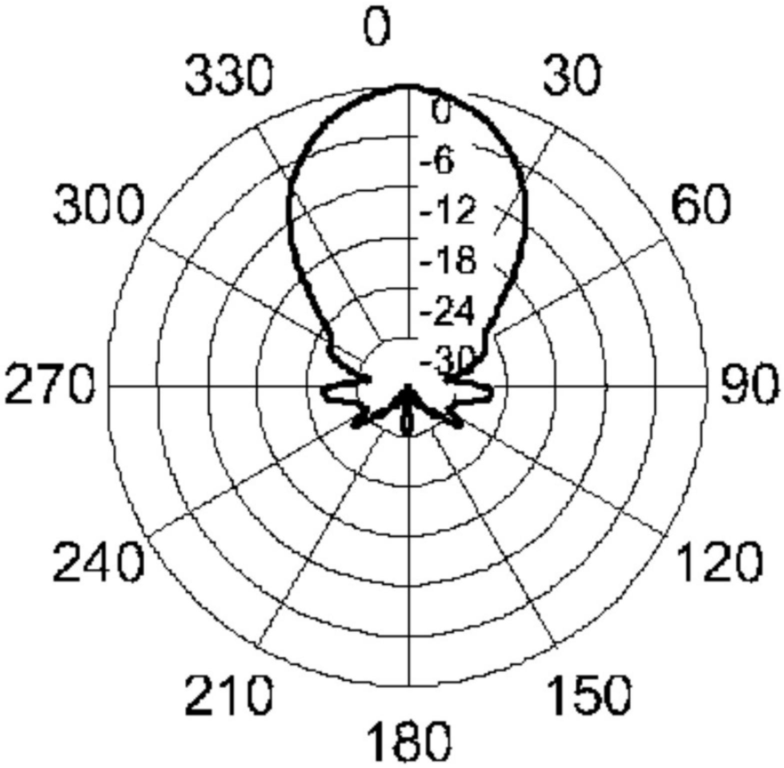


Fig. 20 Ultrasonic sensor pointing diagram

The piezoelectric wafer in the actual ultrasonic sensor is a small disc that can regard each surface point as an oscillation source and radiate a hemispherical wave (wavelet). These wavelets have no directivity. However, the sound pressure at a certain point in space away from the ultrasonic sensor results from the superposition of these wavelets (diffraction), but it has directivity. The picture is the direction chart of the ultrasonic transmitting sensor selected in the circuit.

The pointing diagram of the ultrasonic sensor consists of a main lobe and several side lobes. The physical meaning is that the sound pressure is the largest when the angle is 0°, and the sound pressure decreases when the angle increases gradually. The pointing angle of the ultrasonic sensor is generally 40-80°. This design selects the 45° receiving angle to detect the direction of leakage better.

The working frequency of the sensor is the main technical parameter. It directly affects the diffusion and absorption loss of the ultrasonic wave, the reflection loss of the obstacle, and the background noise and directly determines the size of the sensor.

The determination of working frequency is mainly based on the following considerations:

(1) The absorption of sound waves by the medium is proportional to the square of sound wave frequency, the working frequency shall be lower to reduce the loss of sound wave propagation.

(2) The higher the working frequency is, the more sensitive the sensor's directivity, the shorter the wavelength, the higher the size resolution, and the

'details' are easy to identify. Therefore, the working frequency must be improved from the perspective of measurement accuracy.

(3) From the sensor design point of view, the lower the operating frequency, the larger the sensor size and the more complicated manufacturing and installation.

In summary, the working frequency is selected at 40 kHz so that the sensor has sharp directivity, avoids noise, and improves the signal-to-noise ratio. Although the propagation loss is increased relative to the low frequency, it will not bring difficulties to the reception.

5.2 The development of the design of a portable ultrasound leak detector

The Yamatake Corporation invented a portable leak detector called Leak Detector II. This product is an ultrasonic detection tool with the following configuration. The sound-collecting parabolic hood with high directivity sound collection characteristics. The ultrasound sensor can be detached from the sound-collecting parabolic hood, enabling the mounting of a sound-collecting probe. The Indicator Operations panel is used for expressing detected signal intensity on a bar graph and using numerical values, setting the signal amplification level & headphone volume Note and saving data.

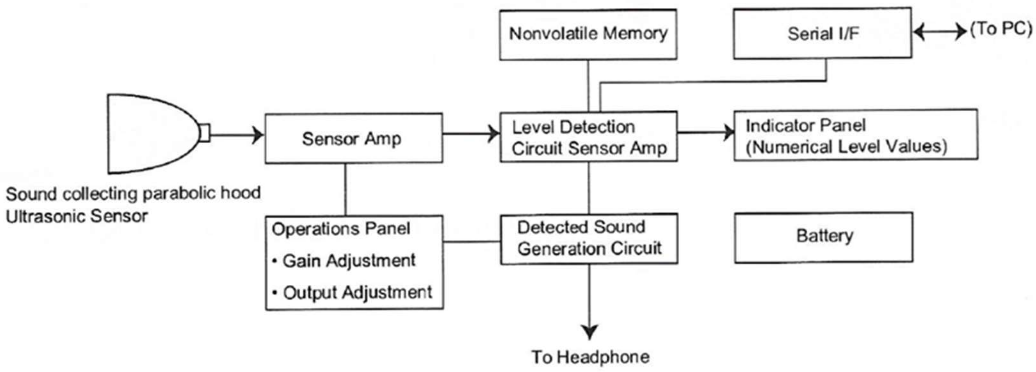


Fig. 21 Leak Detector Il Function Block Diagram

Item	Specifications
Ambient Temperature & Humidity Range	0 to 40 ℃, up to 85% RH (without condensation)
Storage Temperature & Humidity Range	-10 to 40 ℃, up to 85% RH (without condensation)
Received Ultrasound	40 kHz range
Auto Power OFF	Approx. 15 minutes
Indicator	10-step LED, double digit values, 19-step leak volume level
Output	Audible sound converted from received ultrasound via headphone. Variable output volume.
Data Storage	Ultrasound level, leak volume level (in leak mode), and sensitivity setting for 500 data points.
Communications	Serial communications (9P D-sub) 9600 bps
Power	Six AAA nickel-metal hydride (Ni-MH) rechargeable battery
Weight	Approx. 1.3 kg

Table. 6 Specifications

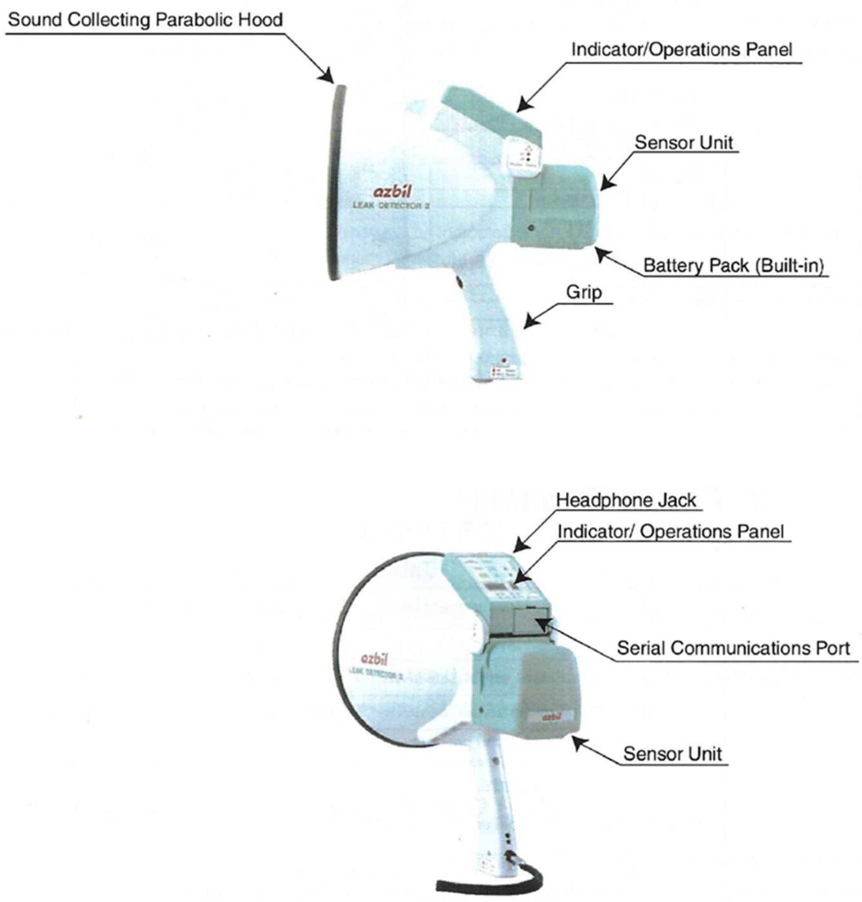


Fig. 22 Main Unit Parts

The ultrasonic portative leak tester “Koloran” (Fig. 23). The leak testing of structures with the ultrasonic leak tester “KOLORAN” allows for facilitating control of aircraft systems. The weight of this device is about 200 gr. The Japanese leak tester “AZBIL” has a weight of 3000 gr. Their sensitivity is equal, and ultrasonic detectors can find leakage at a distance of 50 m.

Fig. 23 The ultrasonic portative leak tester “Koloran”

Fig. 24 Testing of throws defects in fuel tanks of AN-148 plane. It shows using of the capillary kerosine-chalk method and ultrasonic leak testing (the detector “AZBIL”) of the plane’s wing rivets.

The author from Beihang University improved the conventional ultrasonic method for compressed air leak detection by utilizing a directivity-based ultrasonic leak detector (DULD) to locate the leak [45]. This method uses the time delay estimation (TDE) method to break the limit of the nominal frequency and the size of the ultrasonic sensor. Three sensors are organized in an equilateral triangle to receive the sound wave from the leakage. In this method, the location of the leakage can be calculated through the computer and responded to by the users. They found that the leak is often set in step with time delays between each 2 detector signals, and the location error decreases with the distance between sensors.

The average square difference function delay estimator with parabolic fitting is used and two practical techniques are devised to remove the anomalous delay estimates. Experimental results indicate that the location accuracy using the TDE-based ultrasonic leak detector is 6.5–8.3 times as high as that using the DULD. By adopting the proposed method, the leak can be located more accurately and easily, and then the detection efficiency is improved.

Fig. 25 Photo of the directivity-based ultrasonic leak detector (DULD)

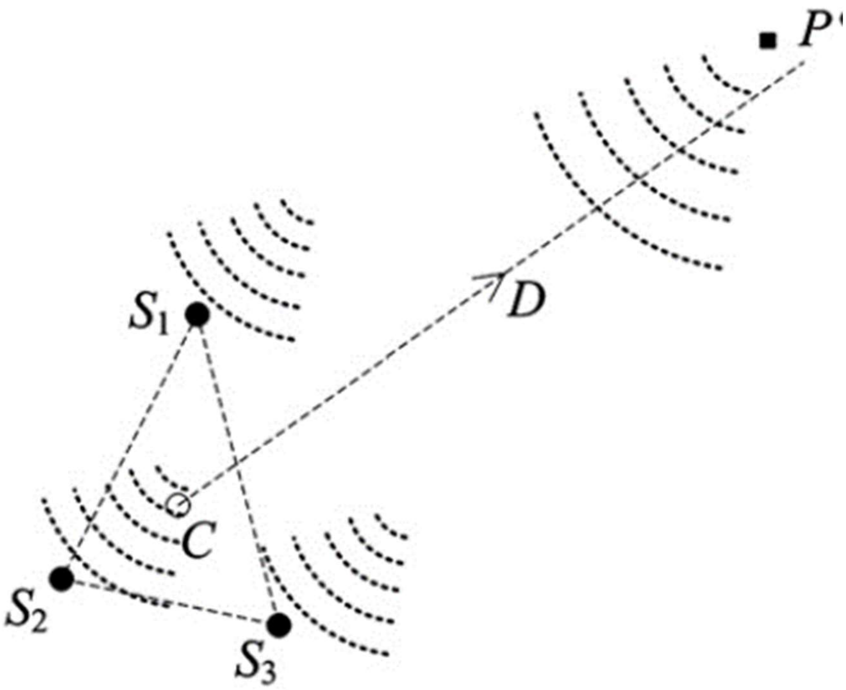


Fig. 26 Schematic diagram of the new ultrasonic leak detection method

Another group also based on the acoustics cascade sound theory, the mechanism of air leak sound producing, transmitting and signal detecting has been analyzed [43]. A formula of the sound power, leak size and air pressure in the spacecraft has been built, and the relationship between leak sound pressure and receiving direction and distance has been studied. The center frequency in millimeter diameter leak is more than 20 kHz. The situation of air leaking from spacecraft to space has been simulated and an experiment of different leak sizes and testing distances and directions has been done. The sound pressure is in direct proportion to the cosine of the angle of the leak to the sensor.

The portable ultrasonic leak detector has been developed, whose minimal leak rate is 0.1 Pa·m3/s, the testing radius is longer than 20 mm, the mass is less than 1.0 kg, and the electric power is less than 2.2 W.

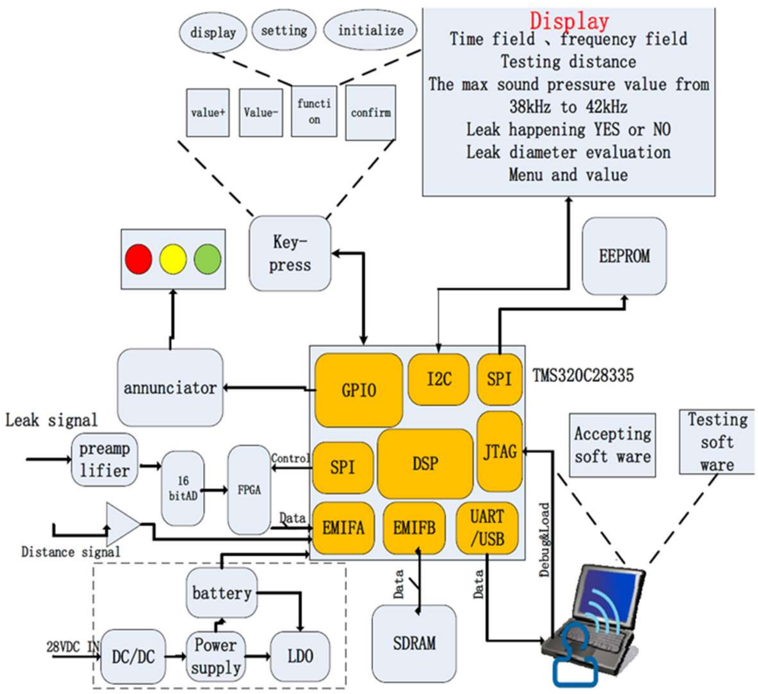


Fig. 27 Diagram of the portable ultrasonic leak detector

Fig. 28 Picture of the portable ultrasonic leak detector

5.3 The detailed design

5.3.1 Overview

This design of a portable ultrasound leak detector indicates to detection of the 40 kHz ultrasound and shows the operator the changing LED light and audio. In this method, the leakage can be found with the air or other gas from the pressurized interspace, leading to ultrasound generation.

This device is used for rough and quick estimates of ultrasound intensity and air leakage volume to increase efficiency. The portable size enables operators to take it to narrow working environments and carry it with other equipment simultaneously.

5.3.2 Functions

The design of the portable ultrasound leak detector enables the operators to:

1. Detect ultrasound in a 40 kHz range
2. Identify the direction of the ultrasound source using the directivity of the sound-collecting hood
3. The ultrasound source can be pinpointed by attaching the sound collector probe
4. See the LED light changing more quickly and hear the buzzer changing more rapidly and loudly, with the leak volume bigger

5.3.3 Specification

5.3.3.1 The mechanical design

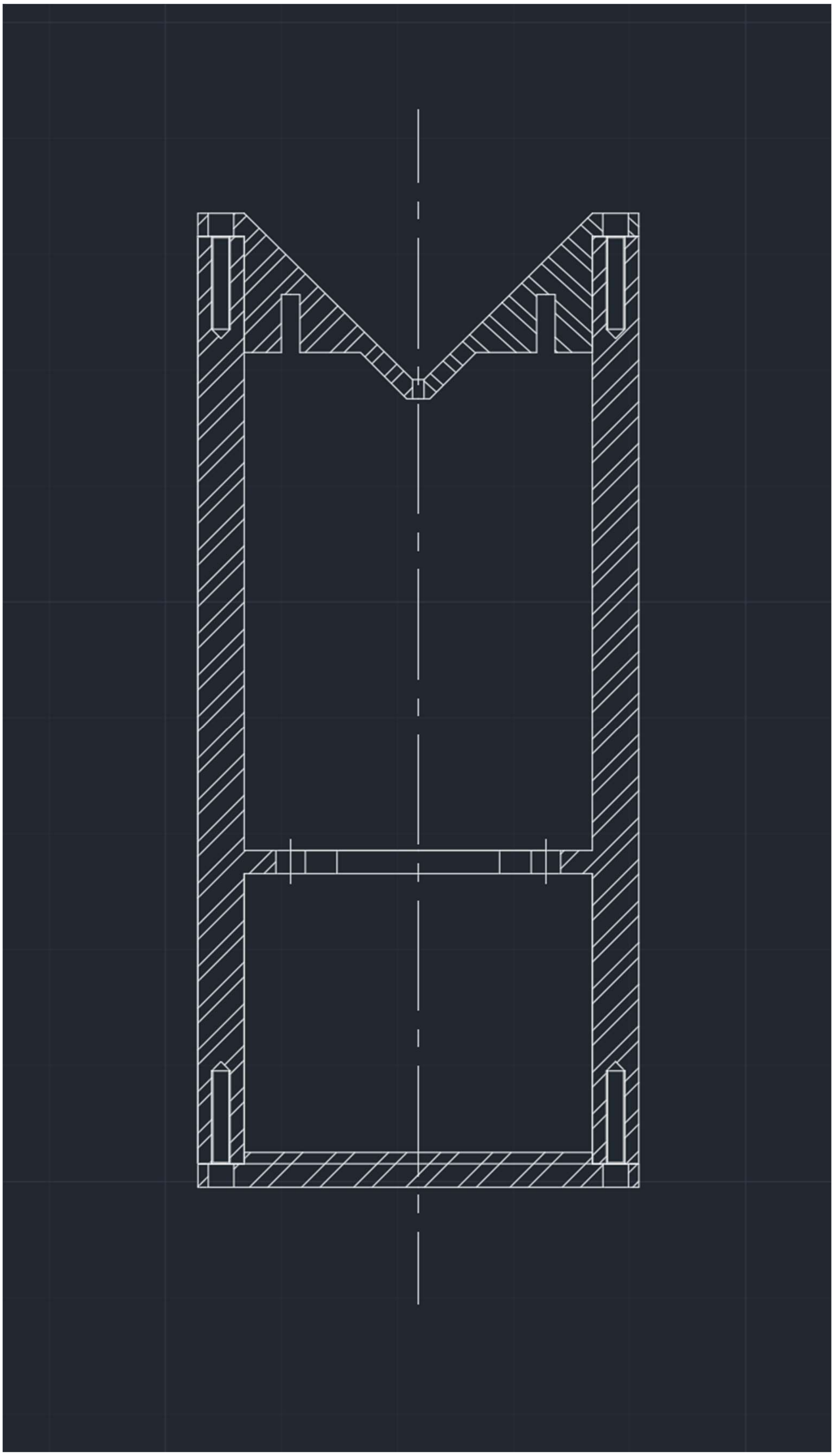


Fig. 27 The mechanical design

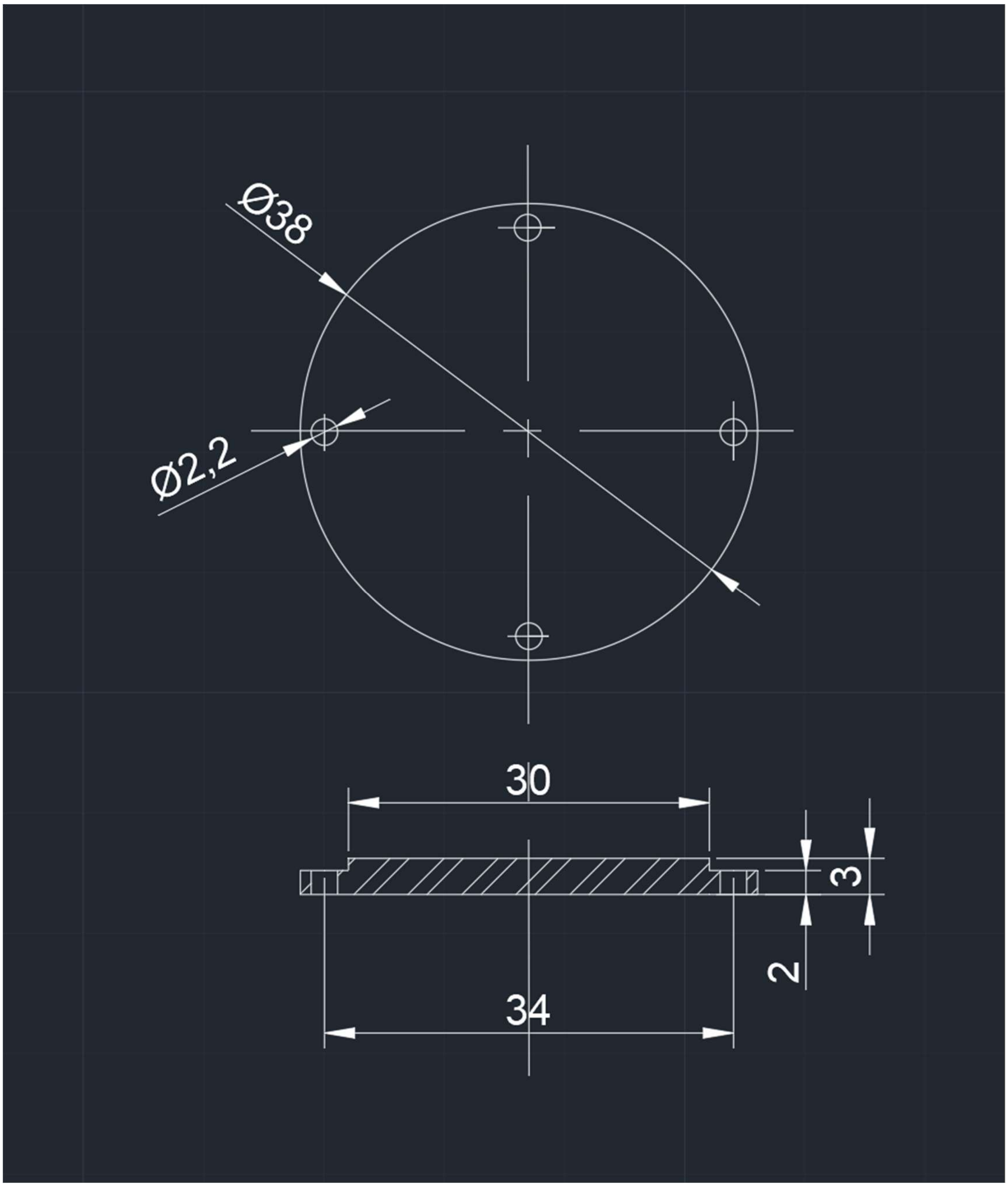


Fig. 28 the mechanical design

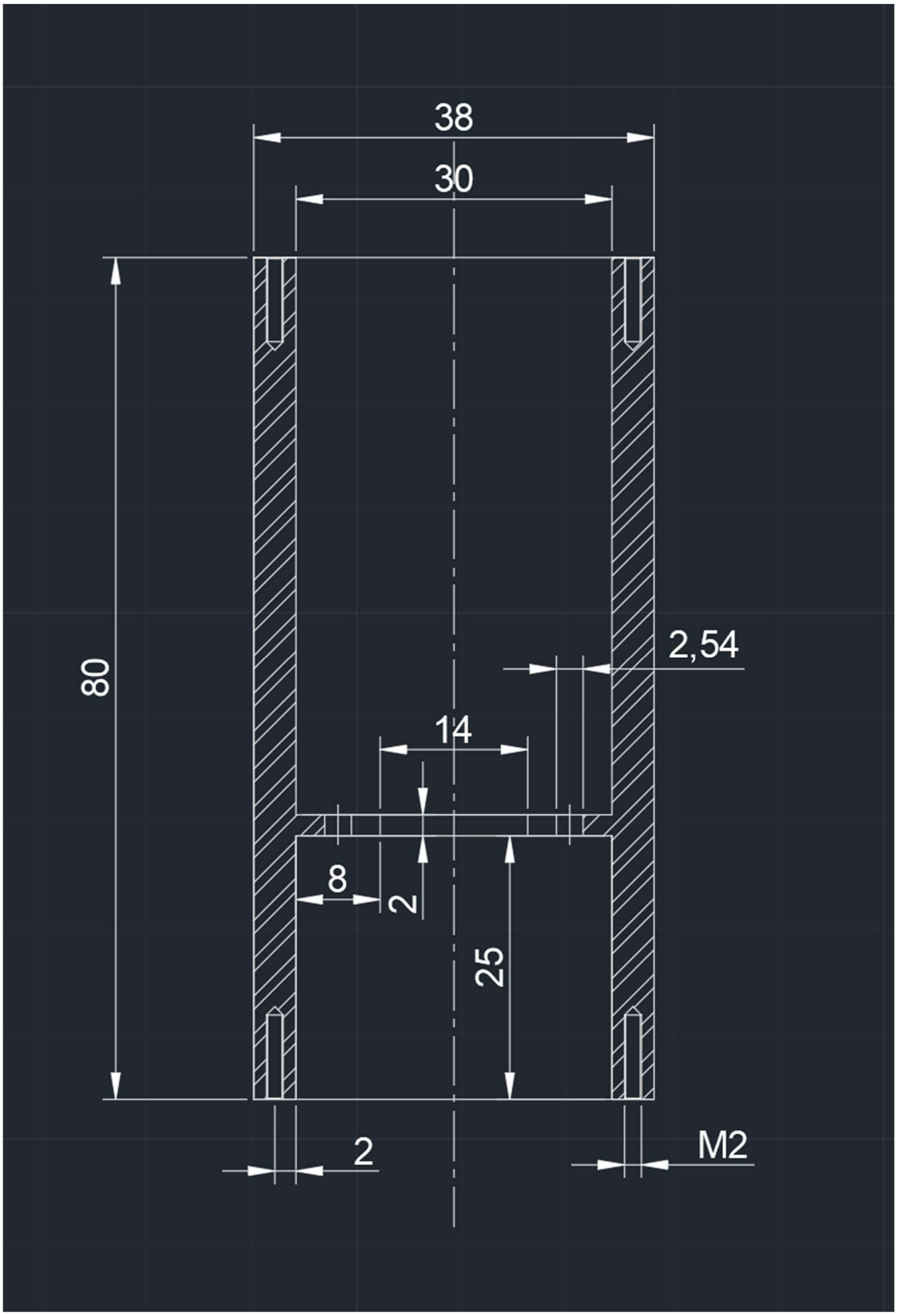


Fig. 29 The mechanical design

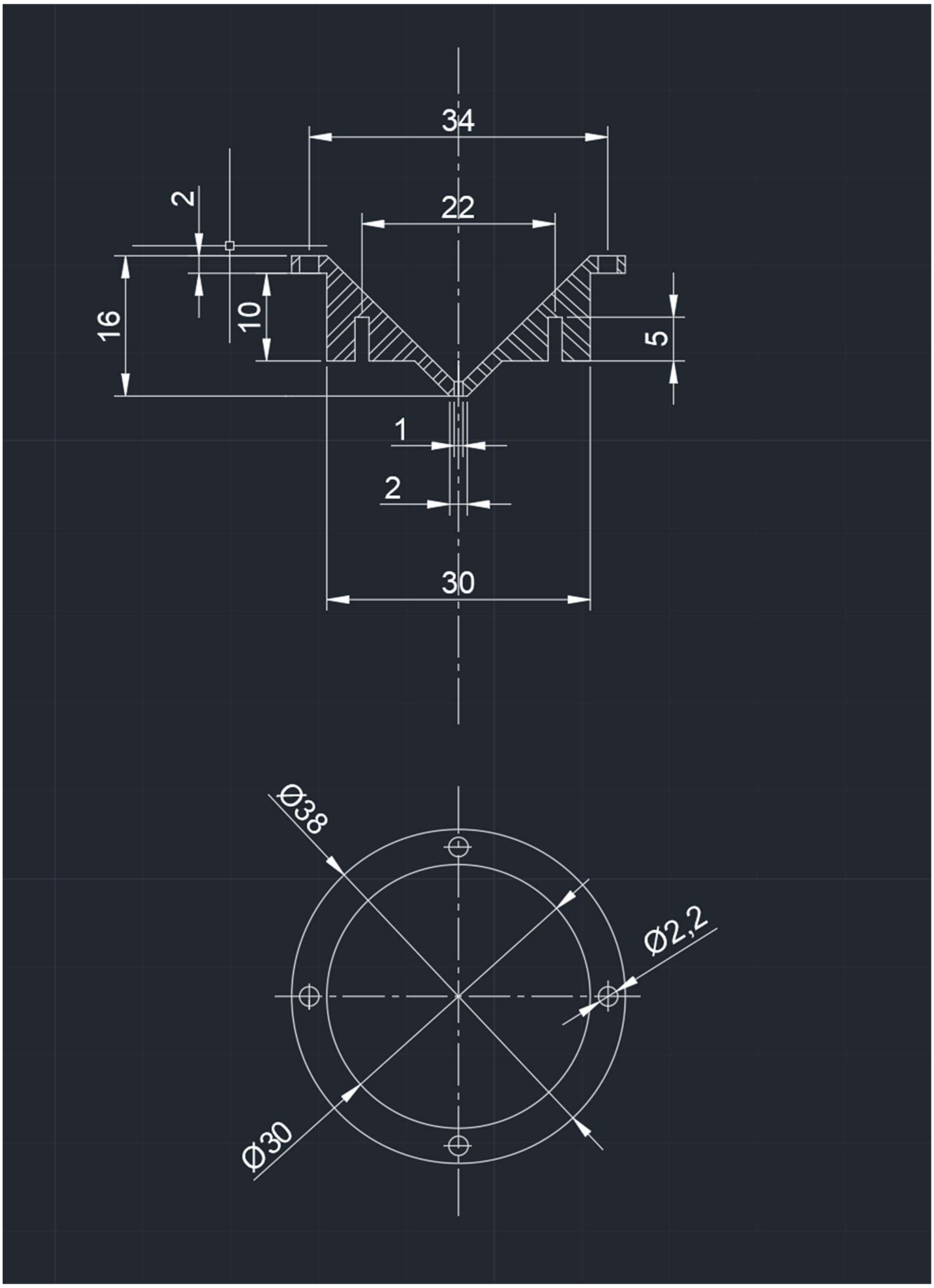


Fig. 30 The mechanical design

5.3.3.2 The electronic design

The simulation design of the system mainly includes two parts, namely the hardware circuit and the software program. The hardware circuit includes a single-chip circuit, an ultrasonic transmitting circuit, an ultrasonic receiving circuit, a power supply circuit, a single-chip reset circuit, and an LED indicator circuit. There is no ultrasonic transmitting circuit in the actual circuit design, but because it is impossible to only have an ultrasonic receiving circuit in the simulation, the ultrasonic transmitting circuit is also included in the simulation design. This design uses the AT89C51 microcontroller as the core of a low-cost, high-precision, miniaturized digital display ultrasonic range finder hardware circuit. The whole circuit adopts a modular design, which is composed of signal transmitting and receiving, power supply, state indication and other modules. The signal of the transmitting probe is emitted after amplification and detection. The timer of the single-chip microcomputer starts timing. The ultrasonic wave returns after being emitted. After amplification and other processes, it is received by the single-chip microcomputer. The counter stops working and displays the relevant state on the LED, and the buzzer emits the corresponding sound.

1.1.1.1 The circuit design and introduction

The circuit diagram includes 51 single-chip microcomputer minimum system, an HC-SR04 ultrasonic ranging module, a LED digital tube display circuit, a buzzer alarm circuit, and a key circuit.

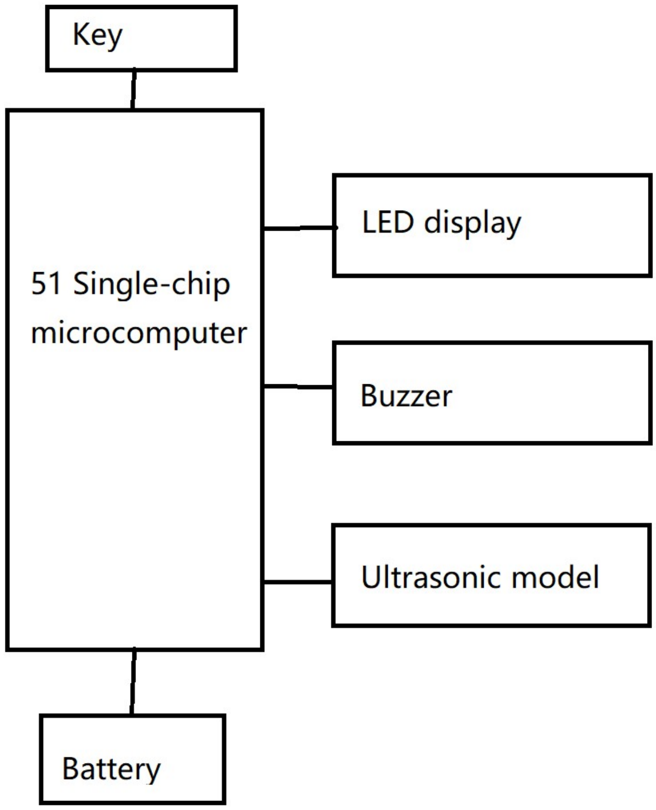


Fig. 31 The design of the circuit diagram

5.3.3.3 The introduction to 51 single-chip system

The single-chip system is also called the microcontroller. It integrates ROM and RAM memory, timer/counter, parallel I / O interface, serial interface, interrupts system, and other functional components in a single chip. Its basic composition is shown in Figure below.

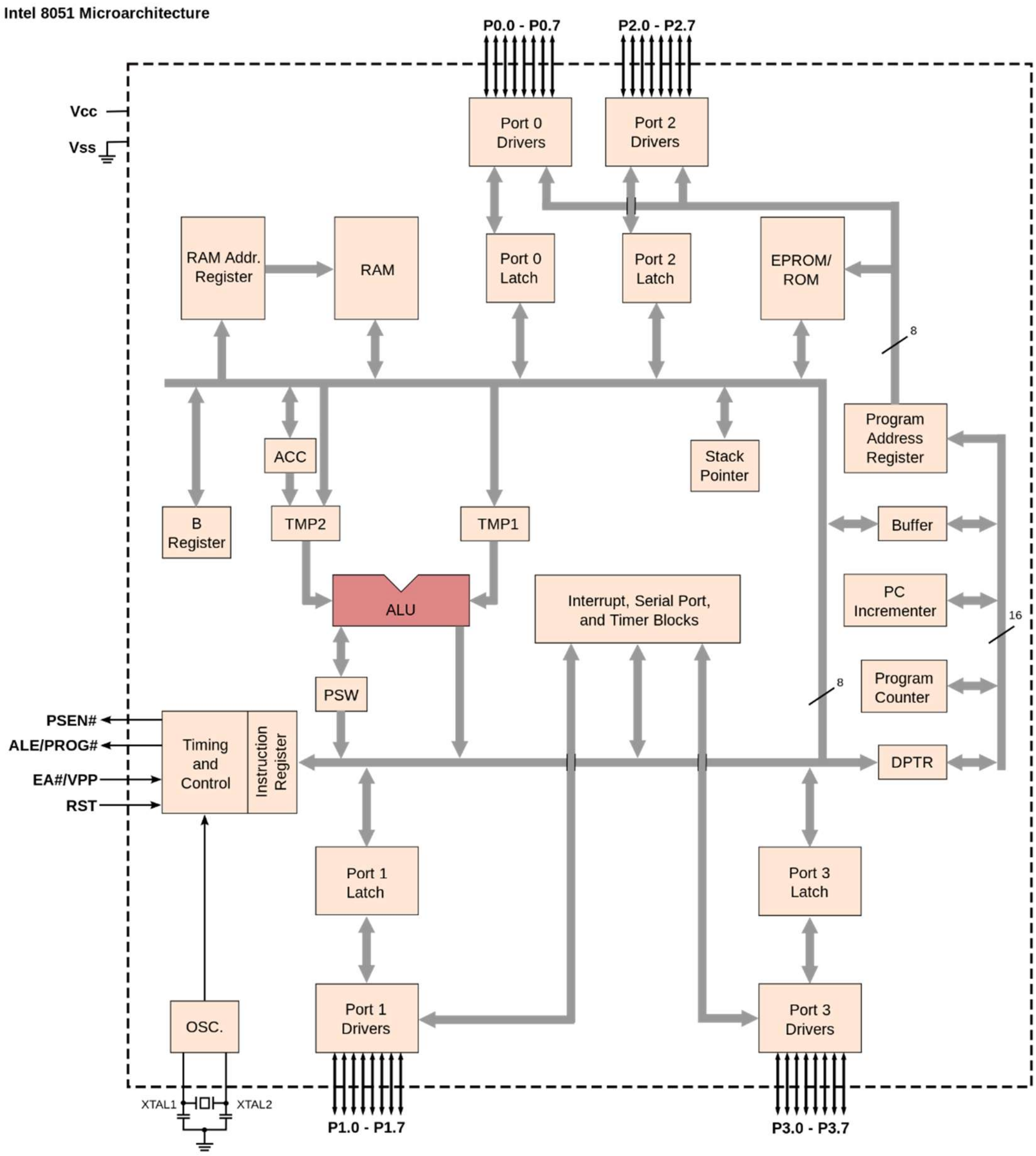


Fig. 32

The CPU is the core of the single chip microcomputer, which is composed of an operator and a controller. The function of the calculator is to perform various arithmetic and logical operations, such as addition, subtraction, multiplication, division, comparison, decimal adjustment and other arithmetic operations, as well as and, or, non, XOR, loop and other logical operations, and send the operation result information to the program state word register to provide a judgment basis for the next operation. The controller includes instruction register, instruction decoder, program counter PC and timing control logic. Its function is to decode the instructions one by one, and send out the control signals required for various operations at the specified time through the timing and control circuits to coordinate the work of each part.

The clock circuit is mainly composed of an oscillator and a frequency divider, which is used to provide a time reference for each working part inside the microcontroller.

ROM memory is used to store program code, tables, constants, etc. RAM memory is used to store various data used during program operation.

The timer/counter can be used to count the external input pulses and can also realize the timing function for the on-chip clock source pulse counting, and control the application target with its counting or timing operation results.

The single-chip microcomputer has multiple parallel I / O interfaces, which can be used for external measurement or control alone, or time-division multiplexing as an external extended address and data bus.

The serial interface is mainly used for communication between single-chip microcomputers or between single-chip microcomputers and host computers. It can also be used for external expansion through serial / parallel conversion.

The interrupt system composed of multiple external and internal interrupt sources provides an important means to meet the needs of measurement and control. In some occasions with high real-time requirements, the use of an interrupt system for data transmission can greatly improve CPU efficiency and achieve real-time control.

5.3.3.4 The introduction to the crystal oscillator circuit

A crystal oscillator is a crystal that converts electrical and mechanical energy into each other to operate in a resonant state to provide stable, precise single-frequency oscillation. Under normal working conditions, the ordinary crystal oscillator frequency absolute accuracy can reach 50 parts per million. Advanced precision is higher. Some crystal oscillators can also adjust the frequency within a certain range by the applied voltage, called a voltage-controlled oscillator (VCO).

Fig. 33

The function of the crystal oscillator is to provide the basic clock signal for the system. Usually, a system shares a crystal oscillator to keep the parts in sync. The fundamental frequency and RF of some communication systems use different crystal oscillators, and the frequency is synchronized by electronic adjustment. The crystal oscillator is usually used in conjunction with the phase-locked loop circuit to provide the clock frequency required by the system. If different subsystems require clock signals of different frequencies, they can be provided by different phase-locked loops connected to the same crystal oscillator.

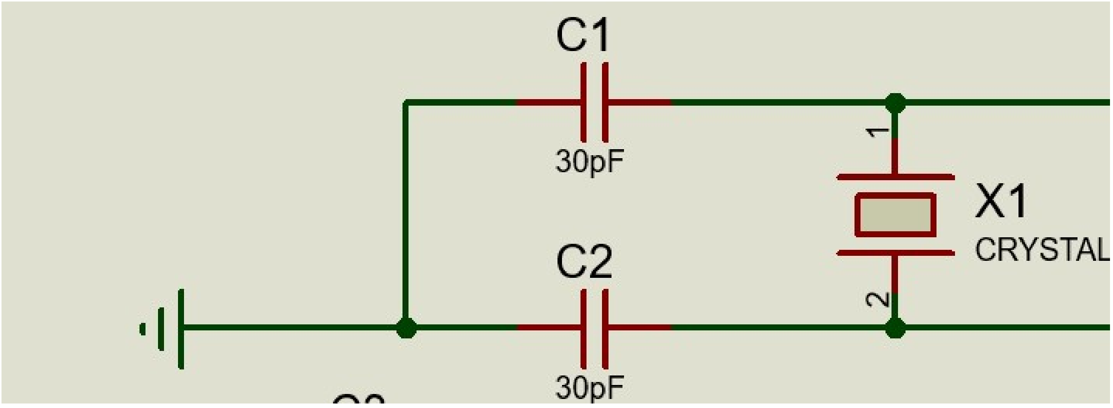


Fig. 34

5.3.3.5 The introduction to the Reset circuit

The principle of the reset circuit: in the ninth pin connected to the high level of continuous 2US can be. In the single-chip microcomputer system, the system is reset once when the system is powered on, and the system is reset again when the key is pressed. If it is pressed again after release, the system will be reset. So you can control its reset in the running system by breaking and closing the keys. After the microcontroller starts 0.1S, the voltage at both ends of the capacitor C is continuously charged to 5V. When the voltage at both ends of the 10K resistor is close to 0V and the RST (reset circuit) is at a low level, the system works normally. When the button is pressed, the switch is turned on. At this time, a circuit is formed at both ends of the capacitor, and the capacitor is short-circuited, so during the process of pressing the button, the capacitor begins to release the previously charged power. Over time, the voltage of the capacitor is released from

5V to 1.5V or even smaller within 0.1S. According to the series, circuit voltage is the sum of the various, this time 10K resistance at both ends of the voltage is 3.5V, or even greater, so the RST pin received a high level.

The working principle of the reset circuit is shown in Figure 35. When the VCC is powered on, the capacitor C is charged, and the voltage appears on the 10 K resistor, which makes the single-chip microcomputer reset. After a few milliseconds, capacitor C is full, 10K resistance on the current drop to 0, and the voltage is 0 so that the microcontroller into the working state. During operation, press S, discharge capacitor C, and the voltage appear on the 10K resistor, making the microcontroller reset. The S is loosened and the capacitor C is charged again. After a few milliseconds, the single-chip microcomputer enters the working state.

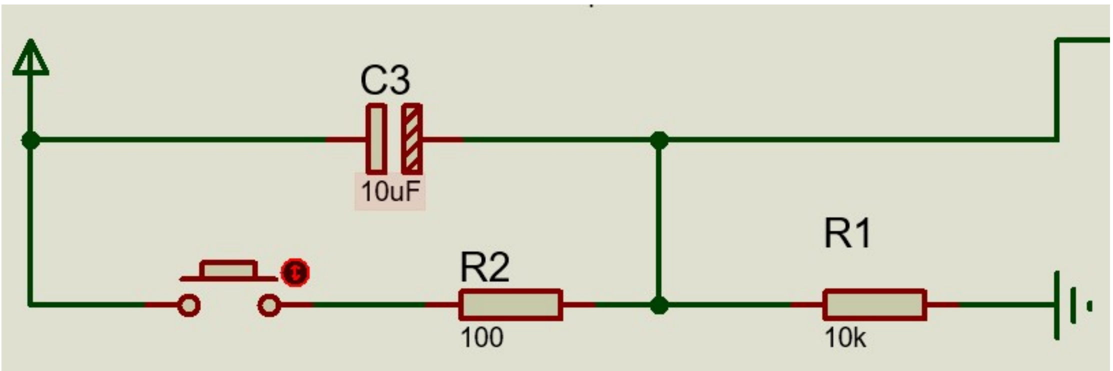


Fig. 35

5.3.3.6 The introduction to the Buzzer

The buzzer is a component we often use. The buzzer cannot be directly driven by the IO of the single-chip microcomputer. Because the current of the buzzer is about 10 mA, the driving ability of the IO is not enough, so the general buzzer is driven by the triode.

The active buzzer drive circuit is shown below. By changing the frequency of the buzzer, the buzzer can emit sounds of different frequencies.

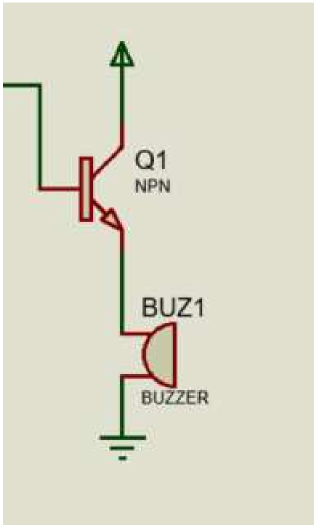


Fig. 36

5.3.3.7 The introduction to the LED

LED is a semiconductor solid-state light-emitting device. It has one-way conductivity. The two poles are P-pole and N-pole respectively. It is also said to be an anode and cathode. As shown in the figure, the anode is connected to the single-chip port, and the cathode is grounded. It only needs to give different levels at the single-chip port. It can control the on-off and flicker frequency of the LED lamp.

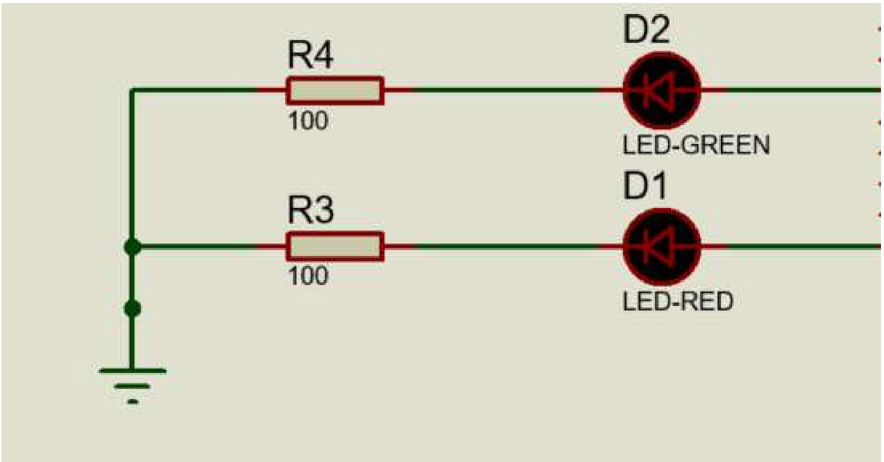


Fig. 37

5.3.3.8 The introduction to the Ultrasonic module

Module pin analysis: It can be seen that the module has four pins, which are:

Vcc : 5V input

Trig : Trigger signal input

Echo : Echo signal output

Gnd : ground

Working principle:

a. Access power and ground to the ultrasonic module.

b. Input a high square wave of at least 10 us to the pulse trigger pin (Trig)

c. After the input square wave, the module will automatically emit eight 40KHz sound waves, while the echo pin (Echo) level will change from 0 to 1 ; (Timer timing should be started at this time)

d. When the ultrasonic wave returns to be received by the module, the level at the echo pin end will change from 1 to 0 ; the time recorded by the timer is the total length of the ultrasonic wave from emission to return.

e. According to the speed of sound in the air (25 °C) 346m / s, you can calculate the measured distance. Distance = high level time * speed / 2

f. Of course, this design does not need to calculate the distance. It is enough just to receive the ultrasound.

5.3.4 Software and circuit design method

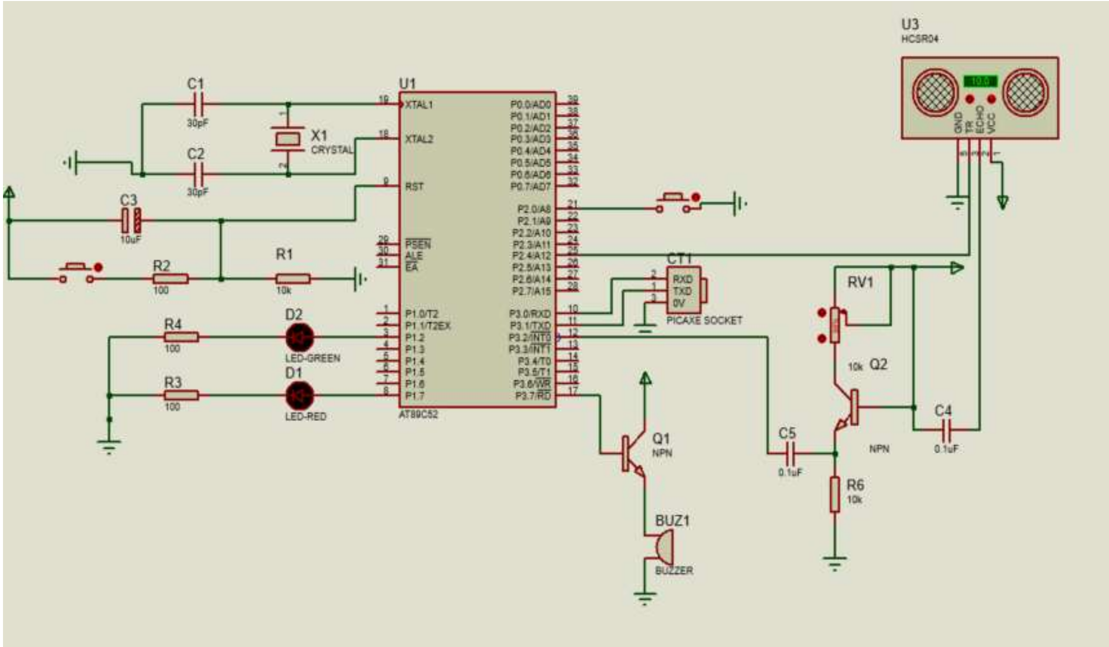


Fig. 38 Circuit diagram of the whole ultrasonic detection system

First, after the system is powered on, press the ultrasonic button. The P2.4 port will send the ultrasonic module a pulse length of not less than 10 us if the pulse length is less than 10us invalid. After receiving the instructions issued by the single-chip microcomputer, the ultrasonic module will send eight 40 kHz pulses from the transmitting end to the receiving end, and then the receiving end will send a pulse after receiving the pulse.

In timing, to use the external interrupt timing, set up the corresponding register can. The potential of the red LED changes after the ultrasonic wave is detected. The red light flashes, and the frequency of the flashing increases as the intensity of the ultrasonic wave increases. And the higher the intensity of the ultrasound, the higher the frequency of the buzzer sound.

5.3.5 Simulation result

The following figure is the simulation circuit diagram of the system. First, after the system is powered on, press the ultrasonic button, and the P2.4 port will send the ultrasonic module a pulse length of not less than 10 us. After receiving the instructions issued by the single-chip microcomputer, the ultrasonic module will send eight 40 kHz pulses from the transmitting end to the receiving end, and then the receiving end will send a pulse after receiving the pulse. The width of the pulse is the time that the ultrasonic wave takes from sending to receiving.

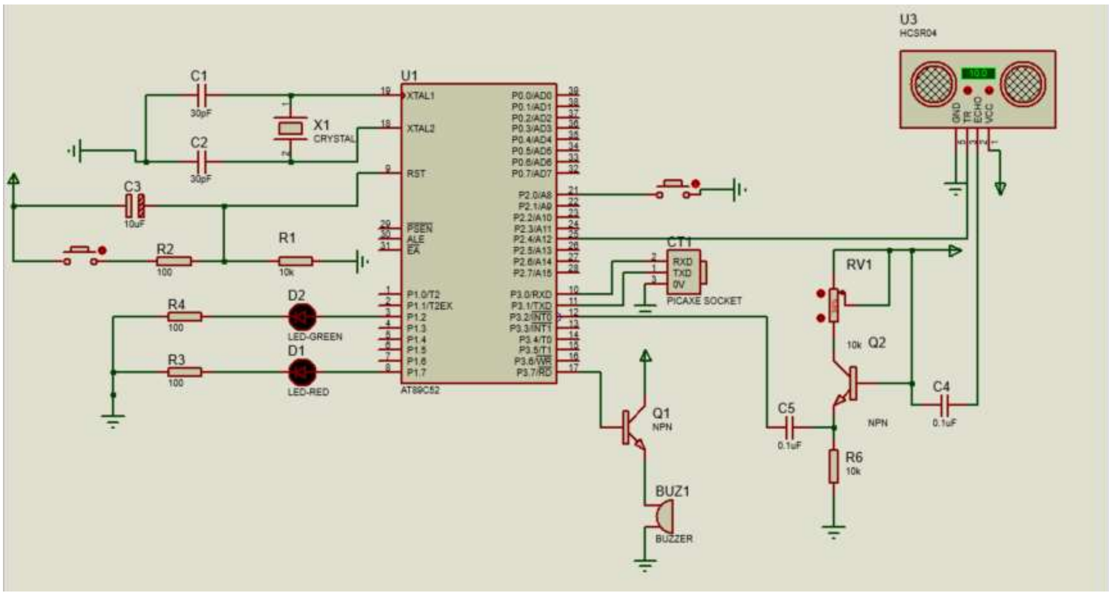


Fig. 39 Circuit diagram of the whole ultrasonic detection system

1. When ultrasonic wave is not detected as shown in the figure, the green light is always on.

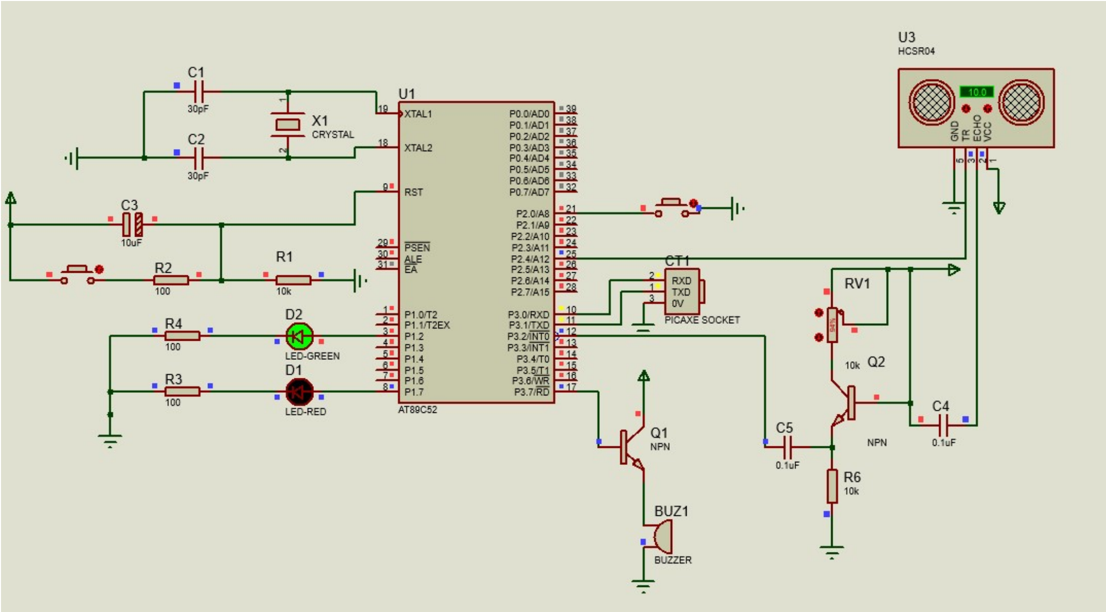
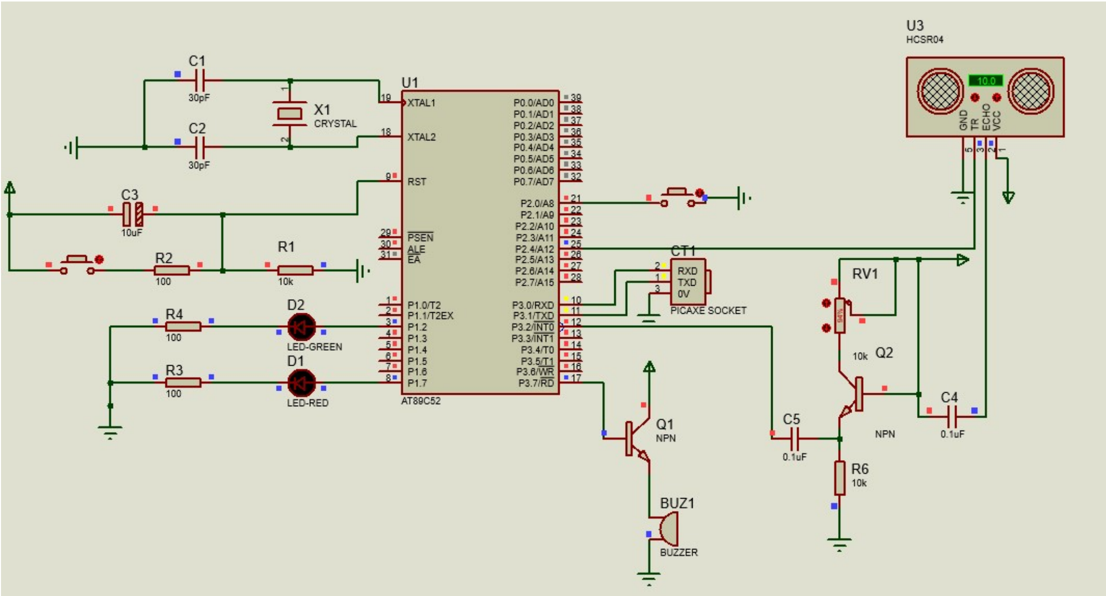


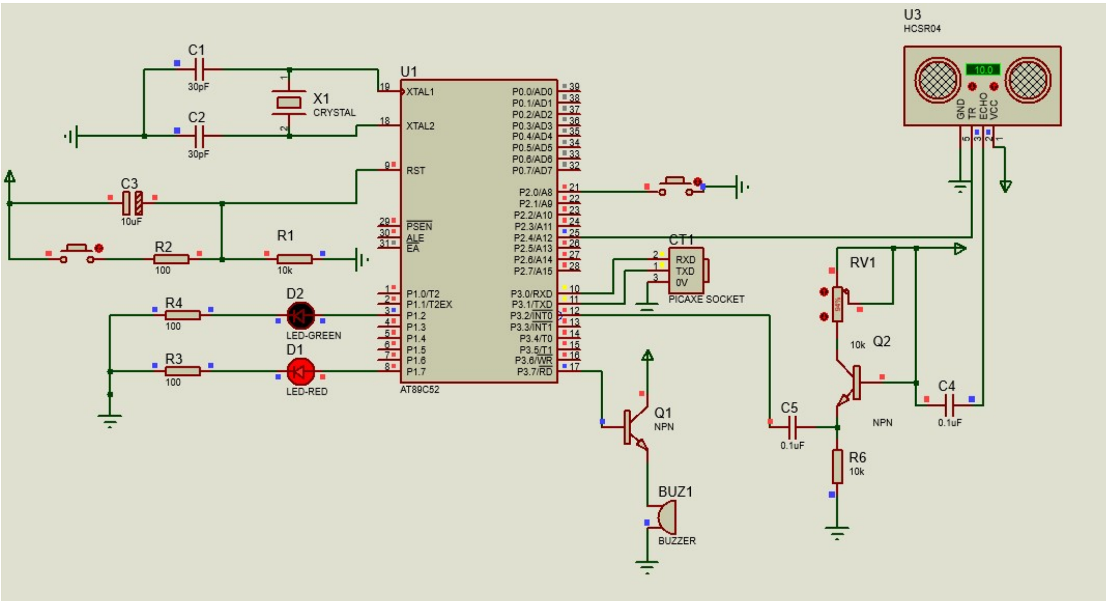
Fig. 40

2. The red light flashes after the ultrasonic wave is detected, as shown in Pic.25 and Pic.26, and the frequency of the flashing increases as the intensity of the ultrasonic wave increases (the intensity of the ultrasonic wave is represented by the distance travelled by the ultrasonic wave). And the higher the intensity of ultrasound, the higher the frequency of the buzzer sound.



U3
HCSR04
C1
30pF
X1
CRYSTAL
C2
30pF
U1
C3
10uF
R2
100
R1
10k
R4
100
D2
LED-GREEN
R3
100
D1
LED-RED
AT89C52
CT1
RXD
TXD
0V
PICAXE SOCKET
RV1
Q2
10k
NPN
C4
0.1uF
C5
0.1uF
Q1
NPN
R6
10k
BUZ1
BUZZER

Fig. 41



U3
HCSR04
C1
30pF
X1
CRYSTAL
C2
30pF
U1
C3
10uF
R2
100
R1
10k
R4
100
D2
LED-GREEN
R3
100
D1
LED-RED
AT89C52
CT1
RXD
TXD
0V
PICAXE SOCKET
RV1
Q2
10k
NPN
C4
0.1uF
C5
0.1uF
Q1
NPN
R6
10k
BUZ1
BUZZER

Fig. 42

5.4 Conclusion

This chapter first introduced the reason for the generation of the ultrasound and discussed the reason for choosing the 40kHz frequency. Then taking an actual sensor as an example to introduce the characteristics of frequency and directionality, which determined the design of the equipment. Before the detail design of the portable ultrasound leak detector, the development of this kind of equipment is introduced to give a basic impression of this equipment.

Then it came to the practical design of this portable ultrasound leak detector, which included the functions, the mechanical design, the electronic design. In the part of the electronic design, every part of the hardware circuit are introduced.

At last the stimulation of the circuit showed the possibility of this portable ultrasound leak detector, where it included the software and circuit design method and results.

6. Startup project

6.1 Description of the project idea

Within the subsection, the following should be consistently analyzed and presented in the form of tables:

- the content of the idea (what is proposed);
- possible areas of application;
- the main benefits that the user of the product can receive (for each direction of application);
- how it differs from existing analogues and substitutes;

Content of the idea	*Directions of application*	*Benefits for the user*
The Design, production, and sale of the portable ultrasonic detector	*Aviation leakage detection*	*Accelerating the detection of the leakage using ultrasound detection* *Portable to fit more application conditions* *High sensitivity to detect the leakage* *Easy to use and swift to handle*
	Tank leakage detection	*Accelerating the detection of the leakage using ultrasound detection* *Portable to fit more application conditions* *High sensitivity to detect the leakage* *Easy to use and swift to handle*

Table 7. Description of the startup project idea

№	Technical and economic characteristics of the idea	(potential) competitors' products/concepts				W (weak side)	N (neutral side)	S (strong side)
		My project	Competitor 1	Competitor 2	Competitor 3			
1.	Price	Low	High	Medium	Meduim			✓
2.	Operation	Easy	Easy	Complex	Easy			✓
3.	Sensitivity	Medium	Medium	High	Meduim		✓	
4.	Size	Small	Large	Medium	Meduim			✓

Table 8. Determination of strong, weak, and neutral characteristics of the project idea

6.2 Technological audit of the project idea

Within this division, it is necessary to conduct an audit of the technology that can be used to implement the project idea (product creation technology). Determining the technological feasibility of the project idea involves analyzing of the following components (Table 9):

- by which technology will the product be manufactured according to the project idea?
- do such technologies exist, or do they need to be developed/improved?
- are such technologies available to the authors of the project?

№	project idea	Technologies of its implementation	Availability of technologies	Availability of technologies to author
1	To detect the leakage in the aircraft	The use of ultrasound detector	completed	Yes
2	When detecting, the equipment indicates the operator with buzz and flash	The use of diagram design	completed	Yes
3	Recording the data	The use of STM32 design	Under developing	No
The chosen technology for implementing the project idea:				

Table 9. Technological feasibility of the project idea

With this table, we can draw the conclusion that we can implemented the project idea.

6.3 Analysis of market opportunities for launching a startup project

Determining the market opportunities that can be used during the market implementation of the project and the market threats that can hinder the implementation of the project allows us to plan the directions of the project development taking into account the state of the market environment, the needs of potential customers and the proposals of competing projects.

№	Market condition indicators (name)	Characteristic
1	Number of main players, unit	9 Customer-investor; CEO; IT team; Mechanical team; Testing operation team; Suppliers; Accountant; Public; Government agencies;
2	Total sales volume, hryvnias/unit	200,000
3	Market dynamics (qualitative assessment)	Increases
4	Availability of restrictions for entry (indicate the nature of restrictions)	N/A
5	Specific requirements for standardization and certification	CCAR; FAR; EASA
6	Average rate of return in the industry (or market), %	15%

Table 10. Preliminary characteristics of the potential market of the startup project

№	The need that forms the market	Target audience (target market segments)	Differences in the behavior of different potential target groups of customers	Consumer requirements for the product
	To provide the able testing equipment for the users.	Aviation Oil storage	We should follow the rule of Aviation law and get certthe-ificate from the authority.	Satiability to operate Cheap Easy to produce

Table 11. Characteristics of potential clients of the startup project

№	Factor	Content of the threat	The company's possible reaction
1.	Equipment	Lack of corresponding supporting equipment	Get assistance from others
2.	Certificate	Need for the certificate	Make full preparation

Table 12. Threat factors

№	Factor	The content of the opportunity	The company's possible reaction
1	Idea	Advanced Design Concept	Further developing
2	Need	Aviation needs faster testing equipment to improve efficiency	Enhance the efficiency in design
3	Cost	Cost controllable	Cut the useless cost

Table 13. Factors of opportunities

№	Competitiveness factor	Justification (of the given factors that make the factor for comparing competitive projects significant)
1	Price	Low price to cut down the cost of operators
2	Operation	Easy to operate
3	Sensitivity	High sensitivity
4	Size	Portable size

Table 14. Level analysis of competition on the market

Compon-ents of analysis	Direct competitors in the industry	Potential competitors	Suppliers	Customers	Goods Substitutes
	Olympus Baker Hughes Elcometer	To get certificate	The project itself	Aviation maintenance cooperation	He sniffer Halogen detector
Conclusions:	Determine the intensity of competition from direct competitors	− are there opportunities to enter the market? Yes - are there potential competitors?	Do suppliers dictate working conditions in the market? Which? No	Do clients dictate working conditions in the market? Which? To get certificate	Buyer's switching costs.

Table 15. Analysis of competition in the industry according to M. Porter

Features of the competitive environment	*What is the manifestation of this characteristic?*	*Impact on the company's activities (possible actions of the company to be competitive)*
1. Specify the type of competition − monopoly/oligopoly/ monopolistic/free	Free	Fierce competition
2. By the level of competition − local/national/…	National	Fit for the law of all the region
3. By branch - inter-industry/ intra-industry	Inter-industry	Comparing to competitors
4. Competition by types of goods: - commodity-generic - commodity type - between desires	Commodity type	N/A
5. By nature of competitive advantages - price / non-price	Not only on price	Not too concentrating on cost
6. By intensity - vintage/non-vintage	Vintage	N/A

Table 16. Justification of competitiveness factors

№	Competitiveness factor	Points 1-20	Rating of competitor products in equal to ... (company name)						
			–3	–2	–1	0	+1	+2	+3
1	Price	20							✓
2	Operation	15					✓		
3	Sensitivity	15					✓		
4	Size	20							✓

Table 17. Comparative analysis of strengths and weaknesses of " The Design, production, and sale of the portable ultrasonic detector "

S *Advanced Design Concept* *Cost controllable*	*O* *Aviation needs faster testing equipment to improve efficiency*
W *Lack of corresponding supporting equipment*	*T* *Difficulty without inappropriate training*

Table 18. SWOT analysis of a startup project

SWOT analysis (or SWOT matrix) is a strategic planning and strategic management technique used to help a person or organization identify strengths, weaknesses, opportunities, and threats related to business competition or project planning. It is sometimes called situational assessment or situational analysis.

This is a method of strategic planning. It is used to develop new areas of business, launch startups, improve business processes of the organization and during project implementation.

№	*An alternative (approximate set of measures) of market behavior*	*The probability of obtaining resources*	*Terms of implementation*
1	*Using the combined laser and ultrasonic method in design*	*Very likely*	*N/A*

Table 19. Alternatives for market implementation of a startup project

6.4 Development of the market strategy of the project

№	*Description of the profile of the target group of potential customers*	*Readiness of consumers to accept the product*	*Estimated demand within the target group (segment)*	*Intensity of competition in the segment*	*Ease of entry at the segment*
1	*The aviation NDT operator The tank storage operator*	*Yes*	*N/A*	*Medium*	*Yes*
Which target groups are selected: choosing a concentrated marketing strategy;					

Table 20. Selection of target groups of potential consumers

Based on the results of the analysis of potential consumer groups (segments), the authors of the idea choose the target groups for which they will offer their product, and determine the market coverage strategy:

- if the company focuses on one segment - it chooses a concentrated marketing strategy;
- if it works with several segments, developing market influence programs for them separately, it uses a strategy of differentiated marketing;

- if the company works with the entire market, offering a standardized program (including product/service characteristics), it uses mass marketing.

№	The chosen alternative for the development of the project	Market coverage strategy	Key competitive positions according to the chosen alternative	Basic development strategy
1	Providing extension of other company	concentrated marketing strategy	Operation and sensitivity	Cost leadership strategy

Table 21. Definition of the basic development strategy

№	Is the project a "pioneer" on the market?	Will the company look for new customers or take existing ones from competitors?	Will the company copy the main characteristics of a competitor's product, and which ones?	Strategy of competitive behavior*
1	No	competitors	Yes, the operation procedures	The strategy of following a leader

Table 22. Definition of the basic strategy of competitive behavior

№	Product requirements of the target people	Basic development strategy	Key competitive positions of own startup project	A set of associations that should form a comprehensive position of one's own project (three key ones)
1	Stability Easy to operate Cheap Easy to produce	concentrated marketing strategy	Portable	Portable, Easy to operate, Low cost

Table 23. Definition of positioning strategy

6.5 Development of the marketing program of the startup project

№	Need	The benefit offered by the product	Key advantages over competitors (existing or those that need to be created
1	For detection	Portable	Portable and low cost

Table 24. Definition of the key advantages of the potential product concept

<table>
<tr><td>Product levels</td><td colspan="3">Essence and components</td></tr>
<tr><td>II. Product according to design</td><td colspan="3">For portable leakage detection with low cost and easy operation</td></tr>
<tr><td rowspan="4">II. Product in actual execution</td><td>Characteristics</td><td>Adv/Dis</td><td>Вр/Тх /Тл/Е/Ор</td></tr>
<tr><td>1. Training
2. Maintenance</td><td>Adv
Adv</td><td>Вр/Тх /Тл/
Тх /Тл/Е/</td></tr>
<tr><td colspan="3">Quality: Meet the entry level of the aviation law</td></tr>
<tr><td colspan="3">Packaging: Meet the standard of the transportation</td></tr>
<tr><td>III.The purpose of the product</td><td colspan="3">For sale</td></tr>
</table>

Table 25. Description of the three levels of the product model

№	The price level for substitute goods	The level of prices for similar products	Income level of the target group of consumers	Upper and lower limits for setting the price of a product/service
1	500USD	1000USD	N/A	500USD to 2000USD

Table 26. Definition of price setting limits

№	Specifics of procurement behavior of target clients	Sales functions to be performed by the product supplier	Depth of sales channel	Optimal sales system
1	Bulk purchases	Promote and sale and training	Producer- the product supplier-Costume	N/A

Table 27. Formation of the sales system

№	*The specifics of the behavior of target customers*	*Communication channels used by target customers*	*Key positions selected for positioning*	*The task of the advertising message*	*The concept of advertising appeal*
1	*The actual operators and the connected aviation cooperation*	*Telephone and Email*	*The connected magazines and conferences*	*To introduce the equipment clearly and introduce the application*	*Stability Easy to operate Cheap Easy to produce*

Table 28. Concept of marketing communications

CONCLUSIONS

This dissertation is divided into 5 chapters. First, his chapter introduces the analysis of existing methods of air tightness control of aircraft structures and systems. Their theoretical foundations, advantages and disadvantages with comparing all the methods which can be applied to aircraft tightness control and indicate their advantages and disadvantages. Also, the development of tightness control in aviation is included.

In the second chapter, this chapter classifies aircraft structures and systems with tightness control and analyze the factors caused accidents and some real accident in history.

In the third chapter, this chapter introduces the development and testing of the technology of control of the tightness of aircraft structures using the method of penetrating substances on samples. First, this chapter analyzes the unclosed constructions where the capillary method is applied as a rule and its physical base. Also, the procedure of the capillary method is attached afterward. Then we show some practical penetrants testing. Due to the high frequency of the bird strike, some models of fast detection for the bird strike are shown.

In the fourth chapter, this chapter introduces the development and testing of the technology of combined methods of air tightness control using capillary and magnetic methods. Then the advantages are discussed to indicate the superiority of this method. Finally, the operation of this method shows the procedure for detection and manufacture. The advantages and disadvantages of each method are compared with table.

In the last chapter, this chapter first introduced the reason for the generation of ultrasound and discussed the reason for choosing the 40kHz frequency. Then taking an actual sensor as an example to introduce the characteristics of frequency and directionality, which determined the design of the equipment. Before the detail design of the portable ultrasound leak detector, the development of this kind of equipment is introduced to give a basic impression of this equipment. Then it came to the practical design of this portable ultrasound leak detector, which included the functions, the mechanical design, the electronic design. In the part of the electronic design, every part of the hardware circuit. At last the stimulation of the circuit showed the possibility of this portable ultrasound leak detector, where it included the software and circuit design method and results.

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