PHOTO-ACOUSTIC PROOF OF TEST GAS IN THE PROCESS OF LEAK DETECTION BY INTEGRAL AND LASER-SCAN SYSTEMS

Lecture held at the
3. special seminar on
tightness test and leak detection
March 11-12, 2003 at the
DGZfP training centre, Dortmund, Germany

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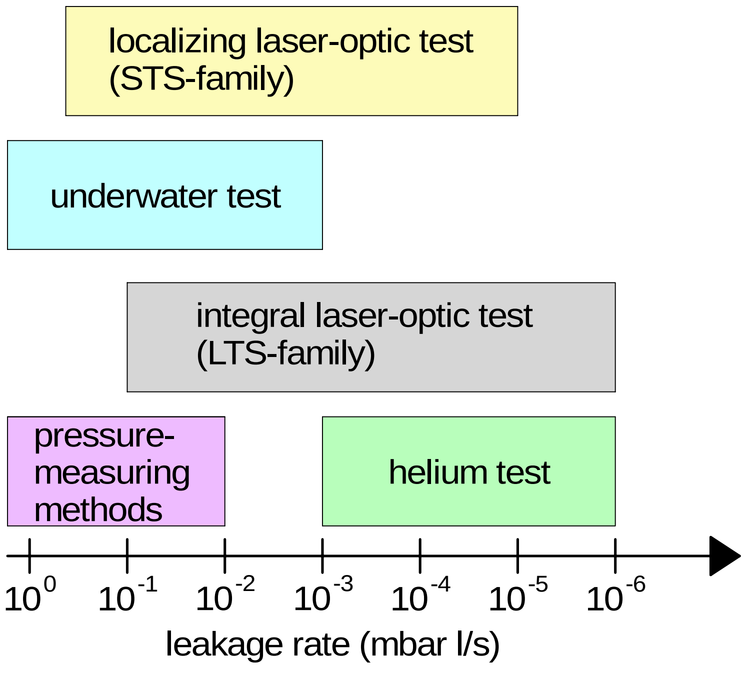
Leak testing is an important aspect of industrial quality assurance. The range of products needing to be tested is extremely wide. As numerous as the products are the requirements to be met by today's test systems. For the users it is, therefore, increasingly important to apply the optimal test procedure to each object to be tested.

1 Summary of Testing Methods

To cover the great variety of applications many different methods have been developed over the years. We can judge the possibilities of laser-optic test systems by a brief look at the most frequently methods of leak testing.



Laser-optic gas detecting systems are used when:

- pressure methods can no longer be applied,
- Leaks must be located without touching them.

Illustration No. 1: Survey of leak-testing methods

1.1 Testing Methods Using Air

Basically, the methods for integral leak detection may be divided into two groups: tests with and tests without test gas. Pressure methods, flow methods, and underwater methods are currently in widespread use. All pressure and flow methods assume that the objects to be tested have a constant volume. If leaking, a pressurized object will show a drop in pressure within a certain time, which is taken as a measure of leakage. In contrast, the flow method tries to keep the pressure at a constant level and measures the necessary air flowing into the object on account of the leakage. The flow method is mainly used for the detection of large leaks. Both, pressure and flow methods, reach their limits as soon as the prerequisite of a constant volume can no longer be guaranteed.

Some objects may change their volumes, if pressurized, so that a drop in pressure or an additional flow of air will occur without any leak. Similar effects are caused by a change of temperature of the test-object or the air used for the test. Such effects have led to refined methods, for example the pressure difference method, where the test-object and a leak-free object are pressurized at the same time and only the difference in pressure between the two is evaluated. Thus it is possible to avoid at least some of the temperature and volume effects. At the moment, pressure methods are being used in industry for leakages of about 10^{-2} mbar l/s. Pressure and flow meters are available on the market for a few thousand dollars. Therefore, pressure methods are highly economical for automatic testing of objects with possible large to medium-sized leaks.

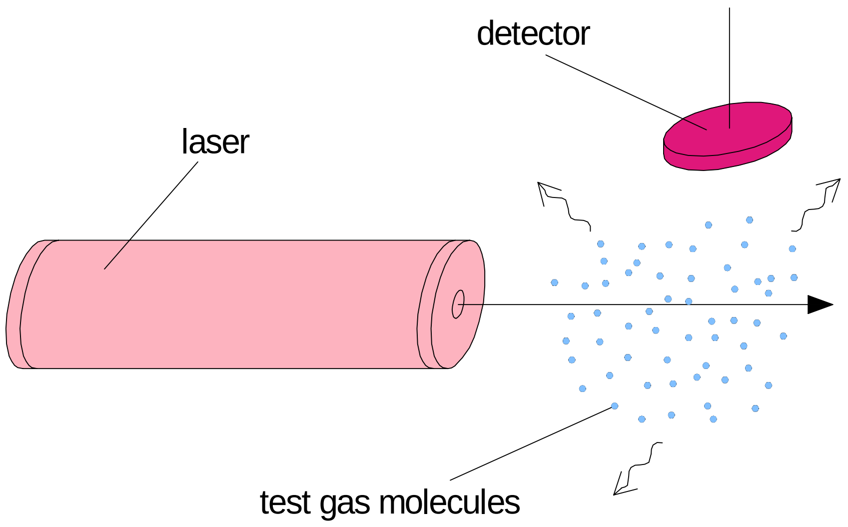
A further method, widespread in spite of, or perhaps because of, its simplicity is the underwater test. Like a bicycle tube with a leak, the test-object is first pressurized and then held under water. The tester looks for rising air bubbles. This rather primitive method allows the detection and localization of relatively small leaks (about 10^{-3} mbar l/s). Additional advantages are the low cost of the apparatus involved and, in most cases, the easy detection. On the other hand, this method also has a number of disadvantages: It cannot be automated and is, therefore, highly labor-intensive. Besides, the results are subjective, and after the test the objects are wet and must be dried.

1.2 Testing Methods Using Test Gases

The second group of testing methods are the procedures using a test gas. All of them have in common that the objects are pressurized with a test gas. Often the testing chamber is first evacuated to assure a faster distribution of the gas, and then the surroundings of the test-object are examined for traces of the test gas. Helium, coolants, and also hydrogen are used as test gases. This method uses mass spectrometers (helium leak tester). For example, the helium molecules sent into the mass-spectrometer are ionized and their concentration is then determined as the measure for the leakage in question. Theoretically, leakages of 10^{-11} mbar l/s can be detected. Normal industrial conditions allow an efficiency of 10^{-6} mbar l/s only, provided the objects are clean and dry. This is required mainly by the high vacuum necessary in the mass-spectrometer (10^{-4} mbar) and in the testing chamber surrounding the test-object (0,1 to 1 mbar). Such low pressures are possible with relatively expensive vacuum pumps only. Because of the low pressure in the mass-spectrometer a possible inadvertent flooding of the test system must be avoided by adequate constructive measures. Integral leak detection with mass-spectrometers, therefore, is not only expensive, but also rather complicated. An interesting alternative are laser-optical leak-detection systems.

2 Photo-Acoustic Gas-Detection Method

The GEMTEC laser-optical leak-testing systems work on an optical basis using laser beams. Often the inert gas sulphur-hexa-fluoride (SF_6) is used; the laser employed is a CO_2-wave-guide laser adjusted to that special purpose.

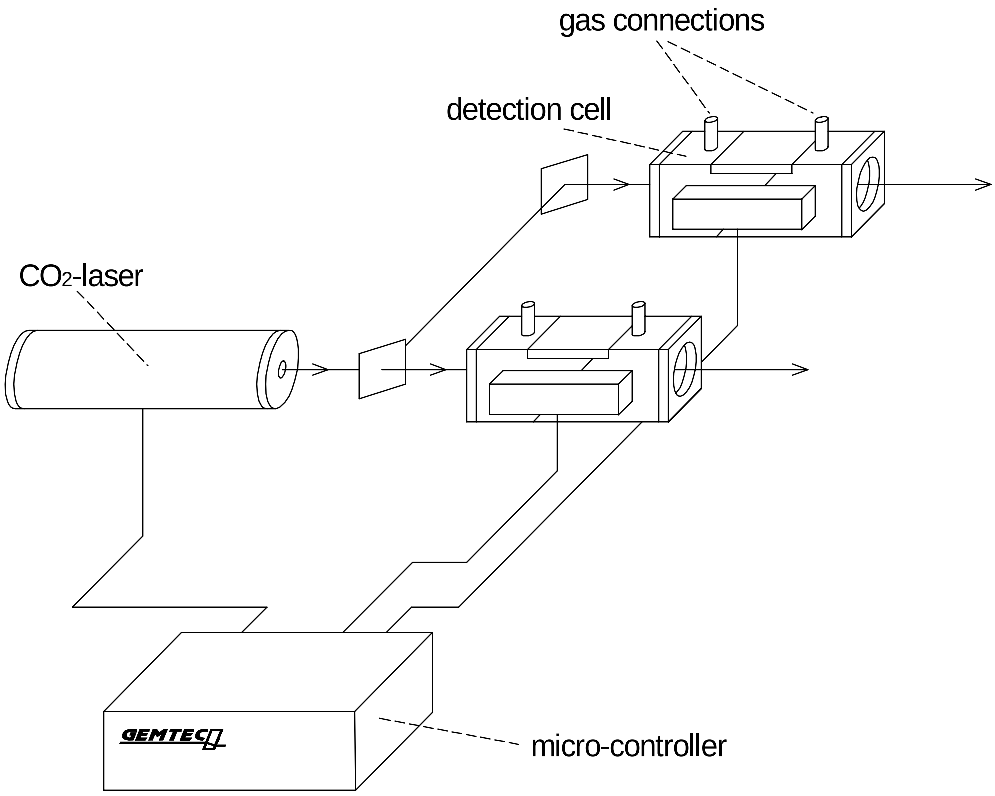


- Determination of the test gas concentration in the gaseous phase (accumulation effects on surfaces are avoided)
- Test gas concentration can be determined within a large pressure-range (10 to 1000 mbar)
- Low detection limit even under unfavorable surrounding conditions.

Illustration No. 2: Laser-optic Test Scheme

2.1 Optical Gas-Detection Systems for Integral Tightness Tests

As with all integral gas detection methods, the gas is taken from the surroundings of the gas-pressurized test-object and transferred to the gas detection cell through the gas connections. Windows in the cell allow the entry of the laser radiation. If the gas (SF_6) is present in the cell, its concentration can be measured and the leakage rate can be computed.



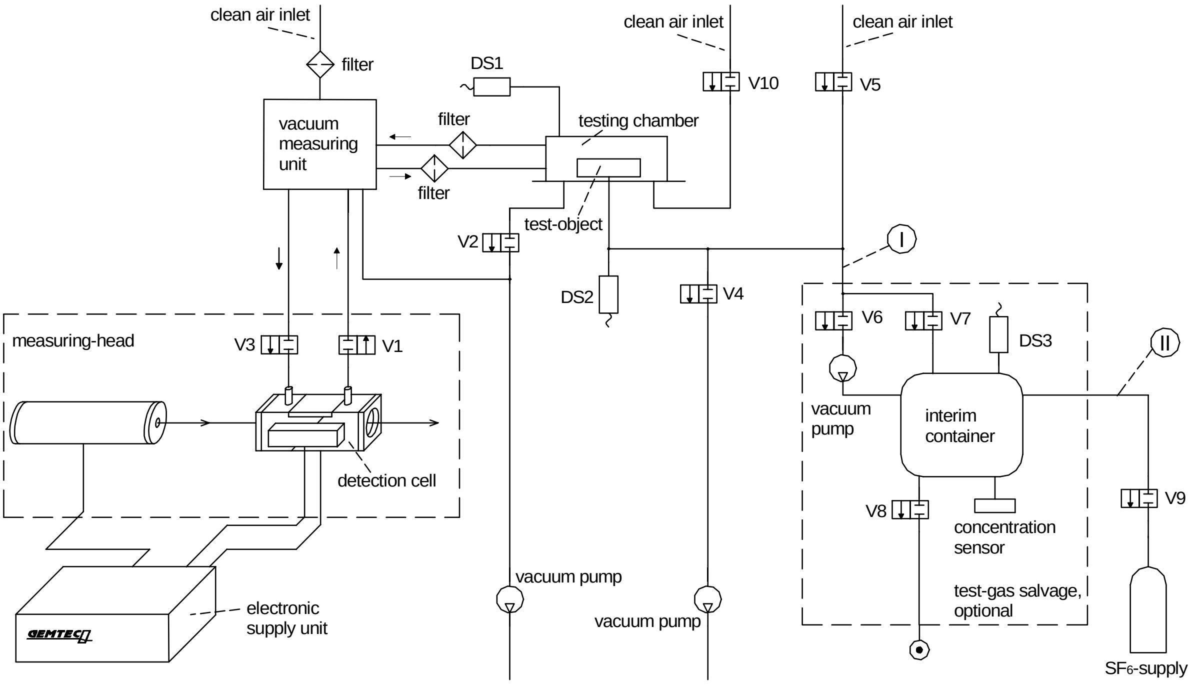
- Compact, robust optic set-up.
- Up to two independently operating detection cells.
- Simple connection to existing testing systems by components commonly used in pneumatics.

Illustration No. 3: Basic scheme of an integral laser-optic test system

2.1.1 Optical Tightness Test at Atmospheric Pressure or under Vacuum

A decisive advantage of these laser-optic leak detecting systems is the fact that the measuring of test-gas concentration can take place at atmospheric pressure and the test data are influenced neither by the temperature nor by the volume of the test-object.

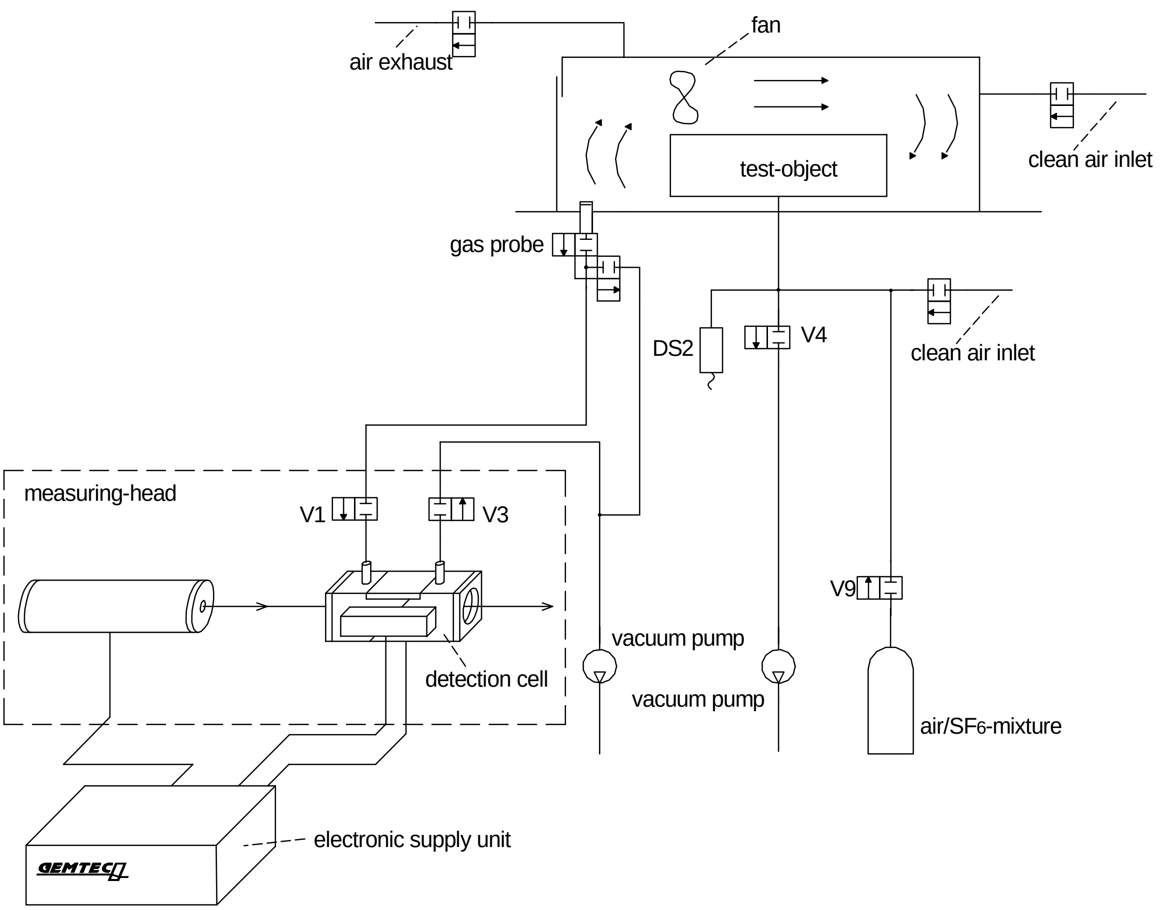
In case the testing chamber is evacuated, a vacuum of about 10 to 20 mbar, reached easily and quickly, will be sufficient. If the test is performed at atmospheric pressure, the air in the testing chamber is whirled by simple ventilators, so that the test gas will quickly be distributed. With a detection sensitivity of 10 ppb (10^{-8}) leakages up to about 10^{-6} mbar l/s can reliably be detected, even under unfavorable industrial condition.



- Very simple and robust set-up.
- high detection sensitivity.
- modest pressure requirements (pressure in testing chamber > 10 mbar).

Illustration No. 4: General set-up for a leak test with vacuum

Because of the completely non-critical vacuum end-pressure and the possibility to work even at atmospheric pressure, laser-optic testing systems are very economical and robust, even if soiled or wet objects are tested. For the entire set-up conventional valves and plastic tubes can be used. Tightness can be assured by o-ring seales, and in most cases a simple oil-sealed vane-type rotary pump will be used as a vacuum pump. Special provisions for large leaks are not needed, since the detection chamber of the system can quickly and effectively flushed with clean air at atmospheric pressure.



- Very simple and robust set-up.
- Possibility to detect leaks quickly and easily, especially in large or vacuum sensitive objects.
- High detection sensitivity.

Illustration No. 5: General set-up of leak testing system at atmospheric pressure

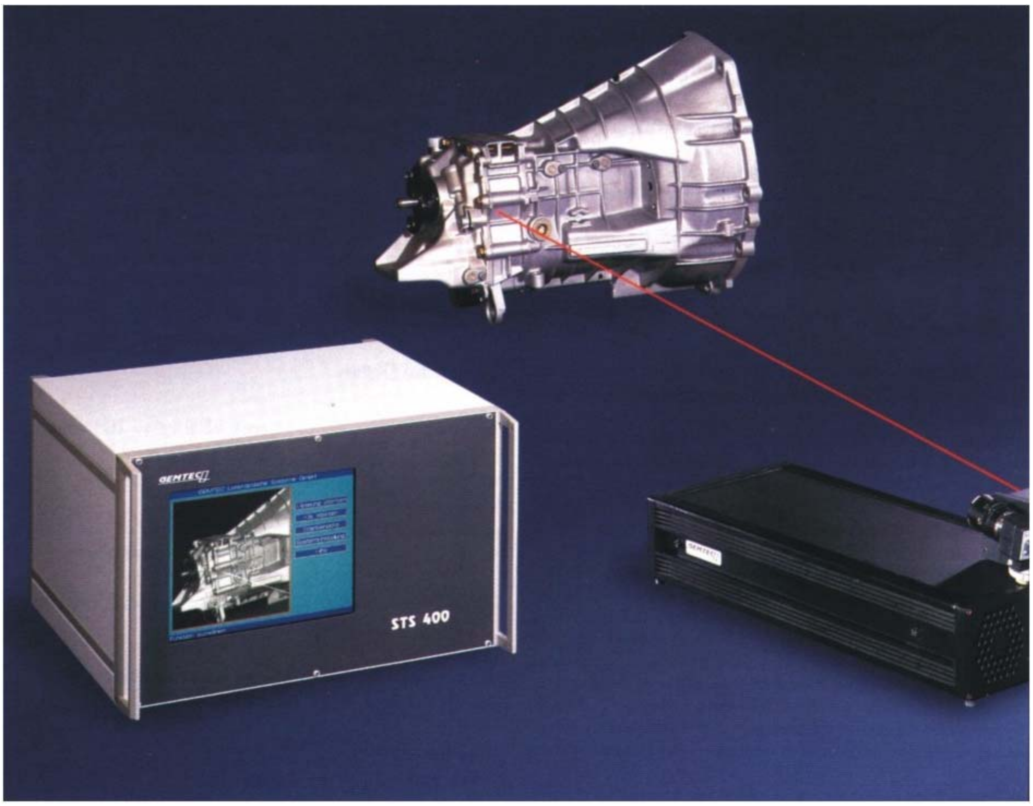
2.2 Optical Laser-Scan Method

Inexpensive mass products found leaking by an integral leak test usually are not repaired. With elaborate products, such as automotive engines, this is impossible, of course. It will absolutely be necessary to find the position of the leaks and to seal them eventually.

In all localizing test methods the test-objects are pressurized with air or test gas. The underwater test, for example, is such a simple procedure. If that test is impossible or undesirable, the object can be sprayed with a soapy liquid, so that the exact location of a leak will be shown by the developing bubbles.

So-called "sniffer"-procedures are used especially in the case of large objects and small leaks. A sensor in form of a capillary through which air or gas is drawn, is held by hand or robot at the suspected area of leakage. If there is a leak, the escaping gas together with the air is drawn into, and confirmed by, the detector. Mass-spectrometers, laser-optic systems, or semiconductor sensors can serve as detectors; helium, SF_6, hydrogen, or various refrigerants (coolants) can be used as a test gas.

The GEMTEC optical leak-testing system STS 400 allows a flexible, automated quality control.



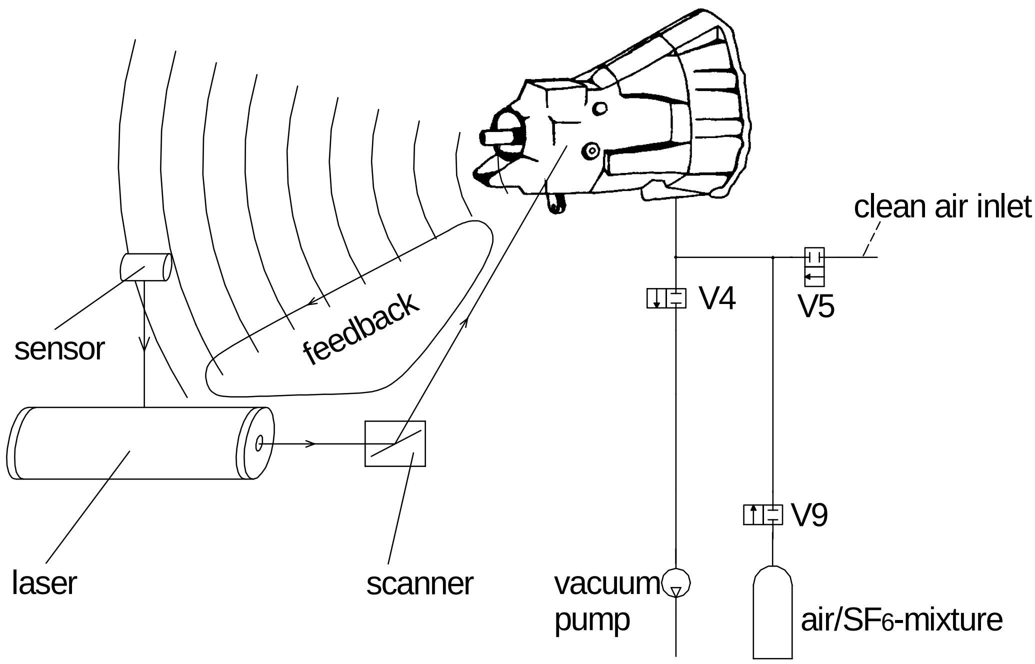
- substitute for underwater tests
- quantification of leakage rates
- visualization of the measuring process

Illustration No. 6: Leak locating system STS 400

Integrated in industrial production processes optical leak-locating systems offer completely new perspectives in industrial quality control.

2.2.1 Functional Concept of the Laser-Scan Method

The optical leak-testing system STS 400 uses a novel optical feedback principle for the localization of leaks (patent pending). For the detection of leaks the test-object is scanned by a laser beam. The beam, like the electron beam in a TV-tube, is moved across the test-object or parts of it. The escaping gas will absorb the light of the laser beam exactly in the moment, when the laser beam reaches a leak. The optical excited testgas molecules, however, quickly lose the absorbed energy and thereby interact with their surroundings. A variety of relaxation processes, such as fluorescent or photo-acoustic effects, can support that process. The lighted test gas now exercises a feedback effect on the optical leak testing system, so that the test gas can reliably and quickly be detected.



- Physical measuring principle: photo-acoustics.
- Feedback principle allows the definite detection of the test gas even in rather noisy surroundings.
- System works up to a working distance of 2.5 meters.

Illustration No. 7: Basic scheme of leak location

In contrast to conventional spectroscopic gas detection methods, where background radiation or elastic stray effects caused by dust particles, or the surfaces of the test-object or other surfaces may all lead to errors, the optic feedback principle realized in STS 400 allows a robust and safe operation under industrial conditions. Since the generation of a feedback reaction on the optical system requires testgas-specific relaxation processes in the test volume illuminated by the laser, the feedback allows a reliable distinction between the detected gas and the test-object surface, which will also absorb part of the laser light. The feedback cycle includes the source of the beam necessary to illuminate the test area, the scanner, a sensitive detector (in the STS 400 system a special microphone), and a control unit. If the test-gas escaping from a leak in the test-object is illuminated during the scanning process, test-gas-specific signals are created. The detector registers those signals together with the ever-present background signals. The control unit sends another signal, which will change, when the detected signals contain symptoms typical for the relaxation processes in the test gas molecules. An intensified original signal, for example, will influence the source of the beam in such a way that the signal again will be intensified. The detector sends out electric signals, which are analyzed by the control unit. The changed signal will again influence the source of the beam and consequently again intensify the original signal. This process will be repeated as often as necessary.

The feedback principle realized in the STS 400 system is similar to the fact that a loudspeaker within the range of a microphone will be detected, as soon as the microphone signal reaches the loudspeaker, because the acoustic feedback reaction generates a whistle. This effect is known from public assemblies or from radio and TV programs, in which the audience may participate by telephone. Applied to the optic feedback system this means that relaxation processes of the test gas are caused by the changing intensity of the laser light. The signals registered by the detector in turn intensify the laser light, which, in case of a leak finally leads to an oscillation of the feedback cycle. Since every known gas detection method can be used for leak detection, it is basically possible to detect almost any technical gas. For robust industrial purposes the inert gas SF_6 and the gas C_2H_4 are well qualified, because of their extreme provableness, when the photo-acoustic effect is applied.

2.2.2 Concept of System STS 400

The optical leak localization system STS 400 is composed of the measuring head and a separate supply and control unit. The measuring head comprises an air-cooled CO_2-wave-guide laser, as well as the scanner unit, necessary for the deviation of the laser-beam. The CO_2-laser beam, invisible to the human eye is superimposed by a red laser beam, by which the scanning of the test-object is made visible. A CCD-camera, attached to the measuring head, allows the presentation of the test-object on a screen. A micro-controller registers the data gained and produces a "leak map". This leak map is now superimposed by the picture of the test-object. The positions of the detected leaks are marked by color on the picture shown on the LCD-screen. This allows a simple evaluation of the test process by the user. A monitor-socket permits the print-out of the test result by an external video-printer as a test record and a map for remedial work.

In addition to such a visual inspection by means of a leak map, the system also allows an automated test procedure via a serial RS-232 interface or Profibus DP. The connection with an automated procedure is simplified by the possibility to define and to number scanning areas by opening corresponding windows. Each area thus defined is then evaluated separately by an OK/Not OK-evaluation. Each testing area can be defined as a separate scanning area. The procedure reduces the test period, whenever certain areas need not be tested, because, as components, they may separately have been tested before.

A test-object with known leaks will normally be used for the calibration of the system. The size of the area in which the test gas is found will then be calculated and automatically compared with the leakage. This is necessary, because the areas may vary, depending on the size of the test-object or the conditions of the test facility. Nowadays a robust design and a clearly arranged instrument panel are absolutely essential for any quality control system. Furthermore, the STS 400 offers the following functions: an integrated self-diagnosing module, a master function, various sets of test parameters, galvanically isolated interfaces protected against excess voltage, an internal real-time clock, an option for remote control, and an error storage function. Thereby a simple and safe operation, but also a complete documentation of all internal parameters will be guaranteed.

3 Examples of application

3.1 Integral optical Tightness Test

Illustration No. 8 shows the testing chamber with test-object holder and adapter unit for the integral leak test of cylindrical test-objects. The detection limit was close to 10^{-8} mbar l/s, the pressure in the testing chamber was 10 mbar and the test-gas ratio in the test-object was 30 percent. The test-object was pressurized for 10 seconds.

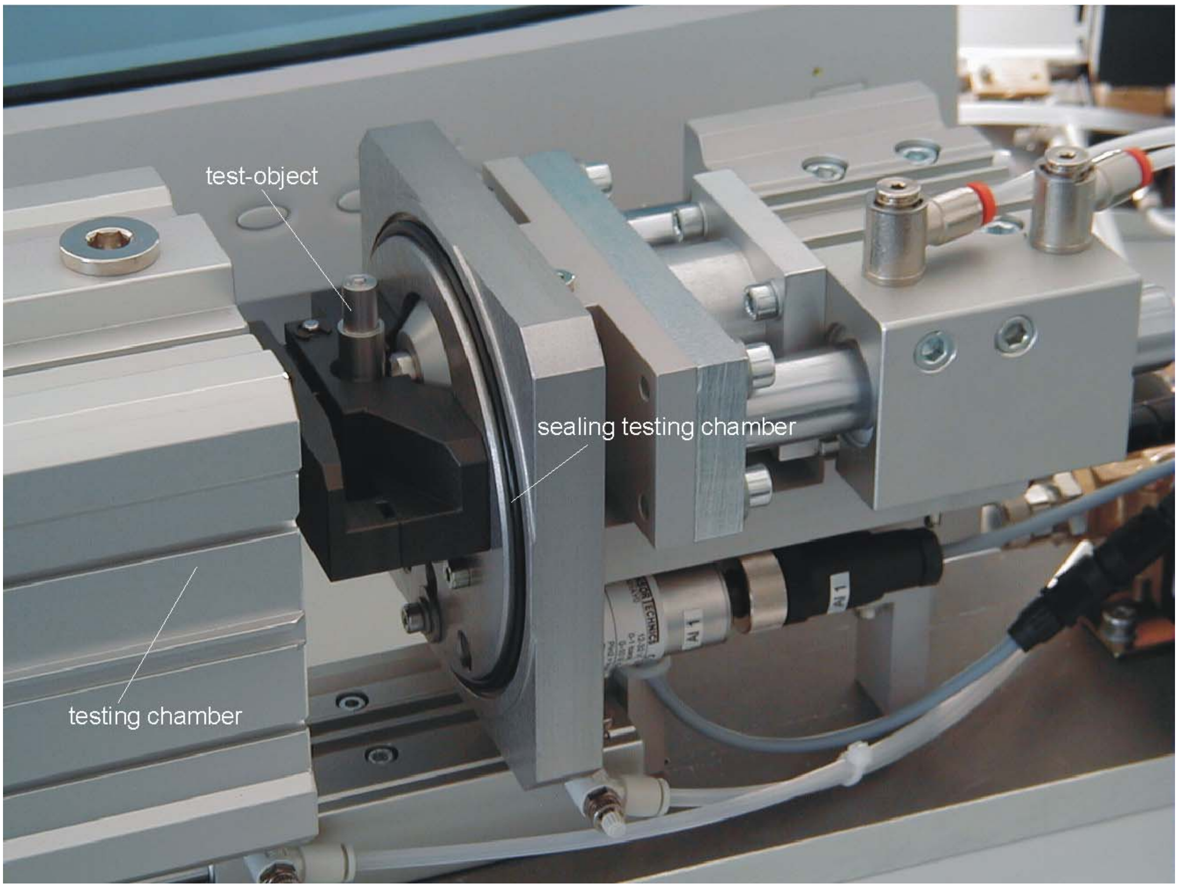


Illustration No. 8: testing chamber with test-object link-up

The test arrangement was planned as a simple manual place of work.

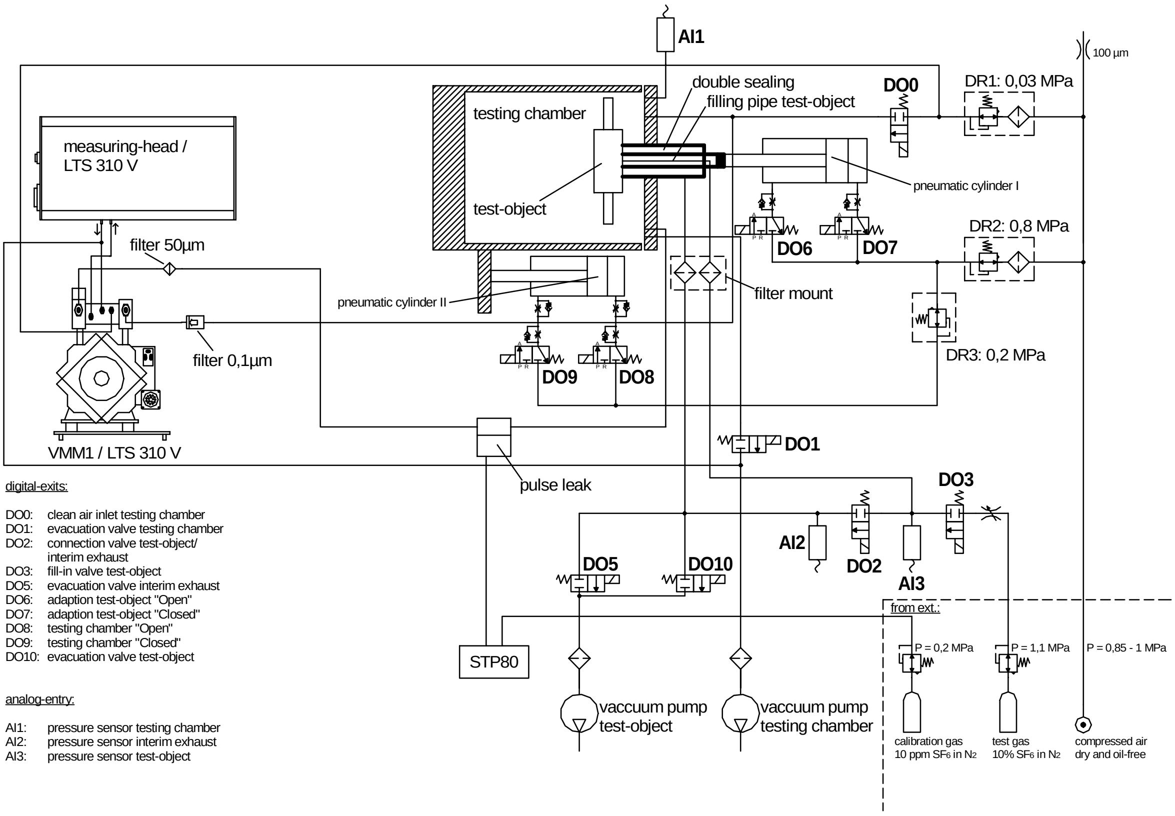


Illustration No. 9: pneumatik plan of the measuring equipping

Illustration No. 9 shows the pneumatic plan. The test procedure was controlled by a PC. The process and the results were documented.

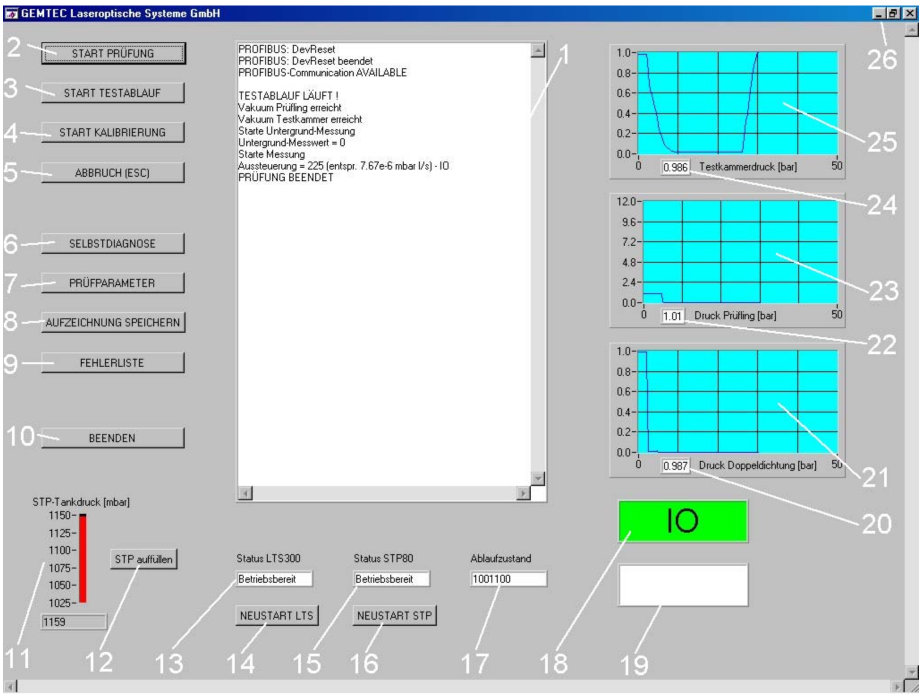


Illustration No. 10: Operation control

Illustration No. 10 shows the operation control. All parameters necessary for the operation, such as changes of pressure or the progress of the test are shown. Illustration No.11 shows the relevant test parameters needed by the operator.

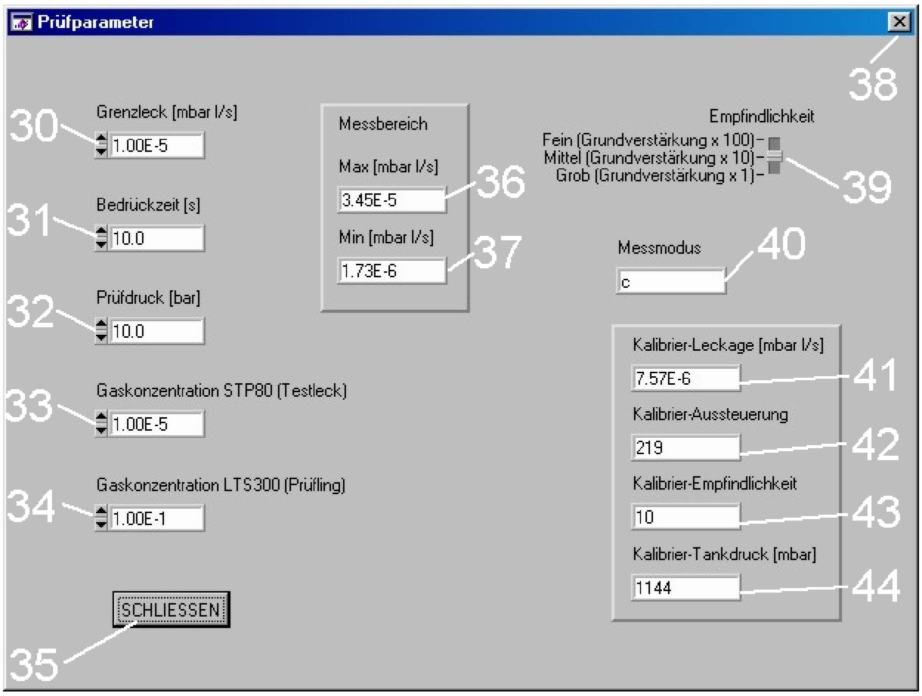


Illustration No.11: Test parameters

Illustration No.12 shows a typical series of measuring results and the values of the calibration leak. During tests 1 to 9 and 15 to 23 the calibration leak was activated, during tests 10 to 14 it was deactivated. The test-object used in those tests was a tight dummy.

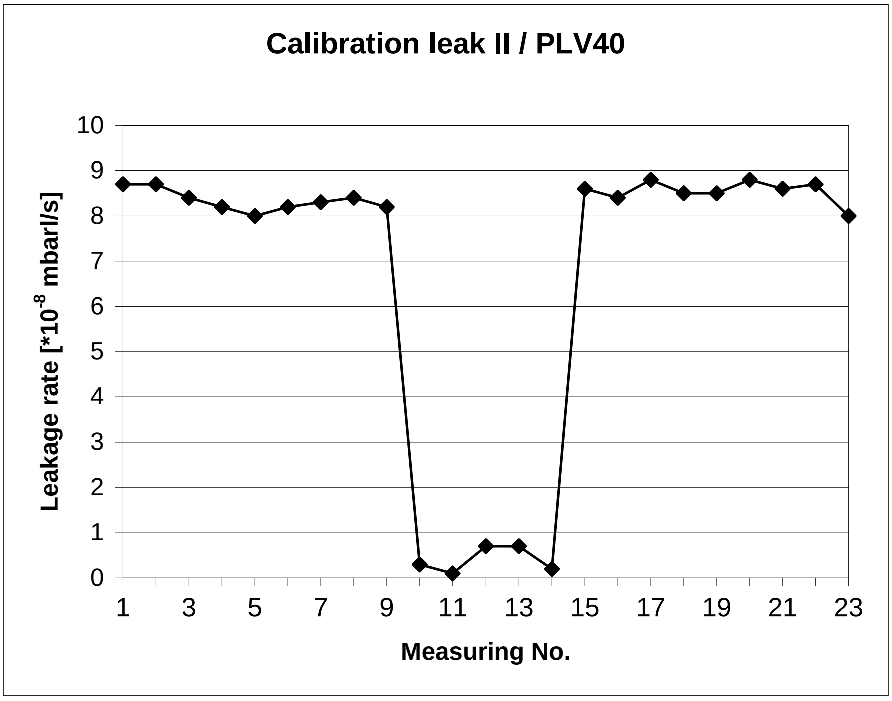


Illustration No. 12: Measurement results with calibration leak

The test-object adapter was equipped with a double sealing with additional evacuation in between the point of adaptation could reach the testing chamber. The double sealing was dimensioned in such a way that leakage up to 1 mbar l/s through the first seal could safely be evacuated.

3.2 Leak Detection through Laser-Scan Method

In order to apply the laser-scan method to complete automotive engines and their fuel-conducting components the test gas SF_6 was dissolved in the fuel (diesel) in a mixing tank. The engine and its components were then filled with this mixture and put under operational pressure (up to 1300 bar). In case of a leak the fuel escapes and releases he dissolved gas, the amount of which is a definite measure for the leakage. Illustration No. 13 shows the scanning arrangement. The measuring head of STS 400 was placed above the engine in order to simplify the arrangement. The detectors were placed above the fuel-conducting components.

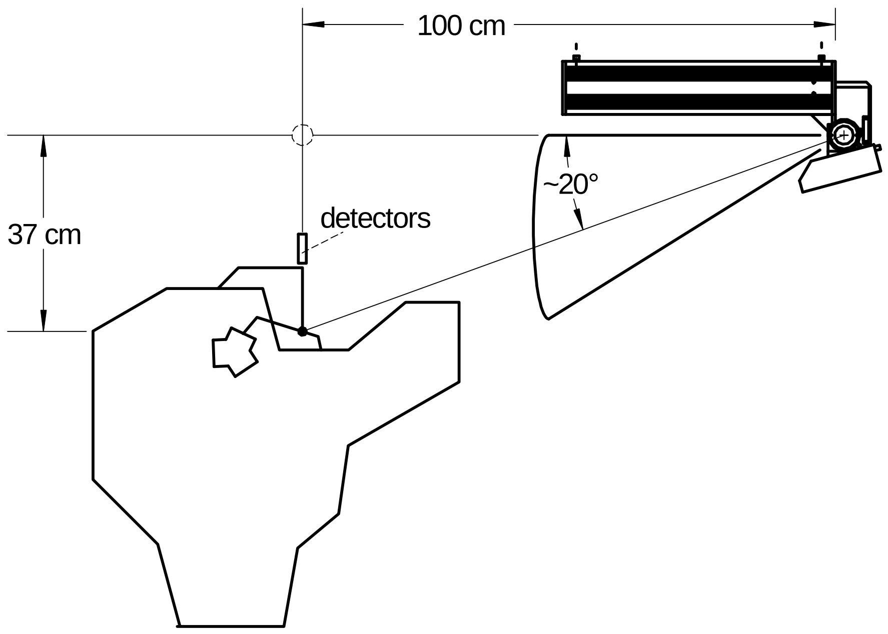


Illustration No. 13: STS 400 M / Scanning setup with a diesel engine

In order to prove the feasibility of this testing method extensive series of tests were conducted. To avoid the blowing-away of the test gas escaping at the leaks the test-object was placed in a testing chamber. Illustration No. 14 shows a typical series of tests with a leaking screwed joint in a closed testing chamber. The importance of the kind of arrangement and the dimension of the testing chamber becomes evident, when a side panel of the testing chamber is removed. This was the situation with the test series shown by illustration No. 15. Although the air surrounding the test arrangement was calm, the test series was visibly influenced by the convection, which can hardly be suppressed when the testing chamber is open.

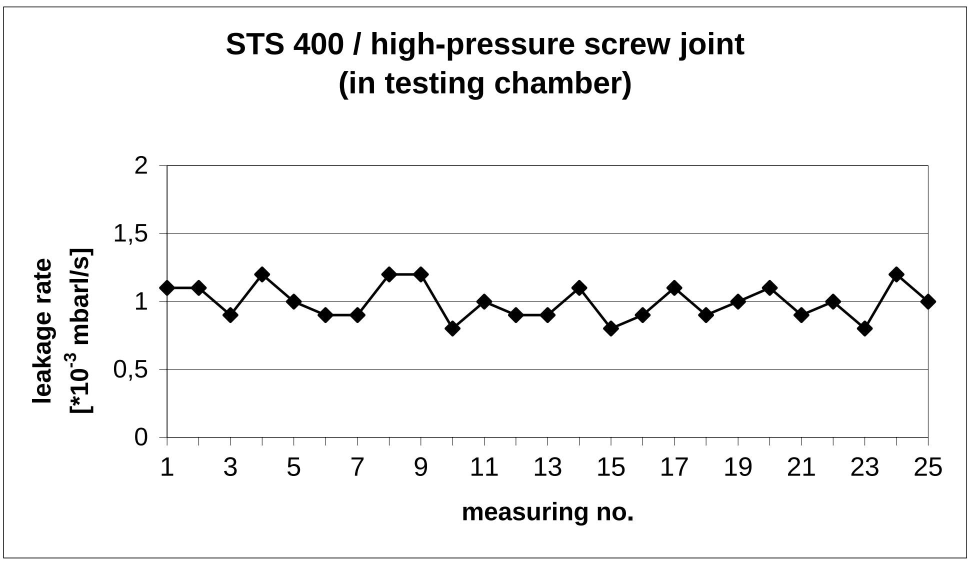


Illustration No. 14: Measurement results with closed testing chamber

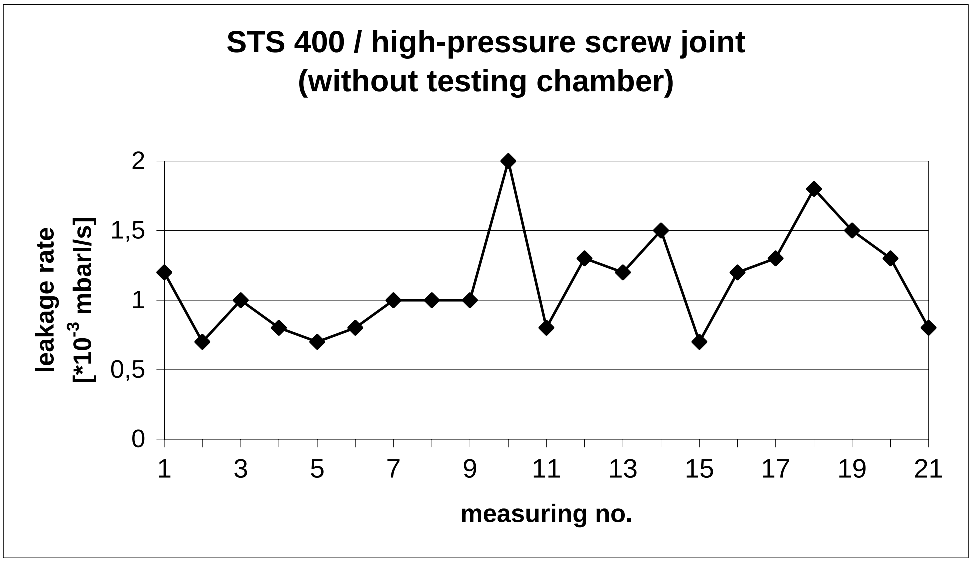
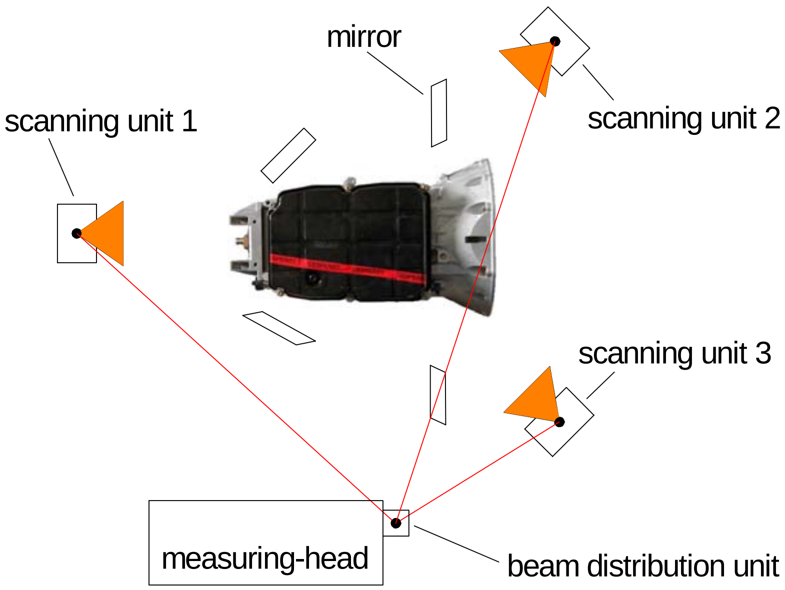


Illustration No. 15: Measurement results with opened testing chamber

Another example of application which was extensively tested, is the localizing leak test of a car gearbox. In this case the test-object was pressurized by means of a test gas. Depending on the possible size of the leaks, a mixture of the test gas and air or nitrogen may be used. In order to detect leakage, it is essential that the gas reaches the outer surface of the object, where it may be lit up by the laser beam. As a rule, this can easily be guaranteed by long enough pressurization. If not all areas of the test-object can be illuminated directly by one laser beam, or if the test-object cannot be turned in such a way that all areas can be illuminated one after another, the optical leak locating system STS 400 M may be employed.

The measuring head of STS 400 M comprises a beam distributor unit, which directs the laser beam emanating from the measuring head towards the scanning mirrors of each separate scanning unit. When an object is examined by STS 400 M, each area to be tested must be visible. Therefore, as many scanning units as are necessary for a complete illumination and scanning of all areas to be examined must be positioned around the object.



- Permits a flexible use of the system, even when test areas are difficult to be reached visually.
- Up to 16 scanning units may be connected.
- Parts filled with liquids (oil) may also be tested.

Illustration No. 16: STS 400 M / Setup of a gearbox test

The examination proceeds in such a way that the various test areas are scanned by the unit that can best reach a particular area. The respective scanning unit receives the laser beam from the beam distributor. Or, in other words, the distributor sends the laser beam emanating from the measuring head to the laser mirror of the presently active scanning unit. The scanning procedure of that unit then happens completely analogous to the scanning procedure of STS 400.

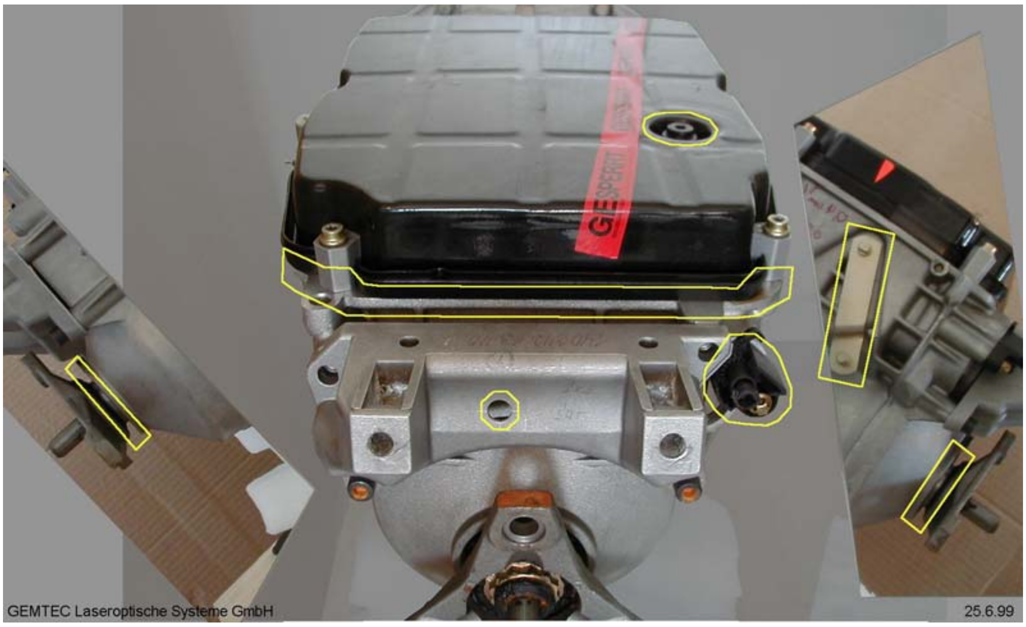


Illustration No. 17: STS 400 M / Scanning view No. 1

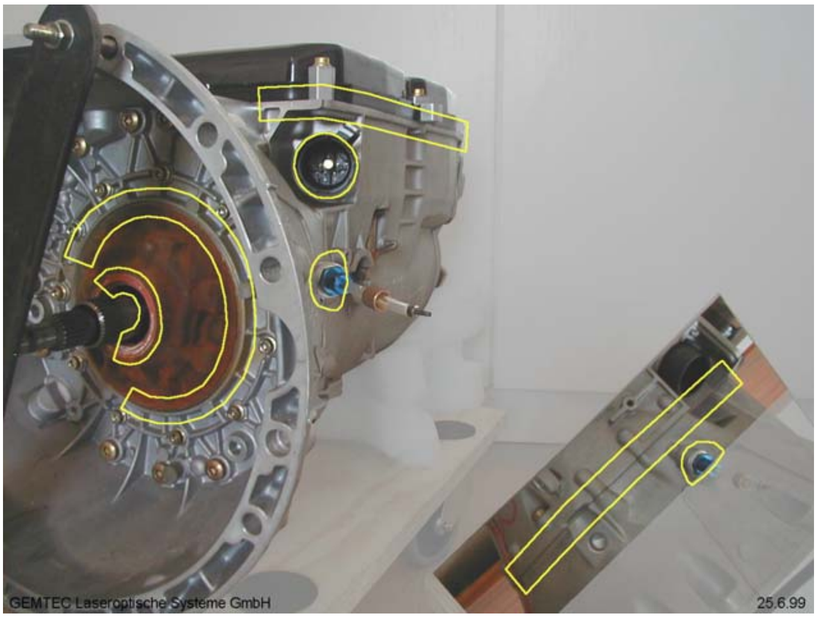


Illustration No. 18: STS 400 M / Scanning view No. 2

When an automotive gearbox, for example, is tested, the STS 400 M system makes it possible to scan all relevant areas by one measuring head, a distributor fixed to that head, and three scanning units. The entire procedure can easily be controlled by means of the pictures supplied by the three scanning units. As with STS 400 the areas to be scanned can be marked by color. To minimize the number of scanners, additional areas may be scanned by a laser beam redirected by a mirror. Thus all relevant areas will either be tested directly by a scanning unit or by a scanner and via mirrors.

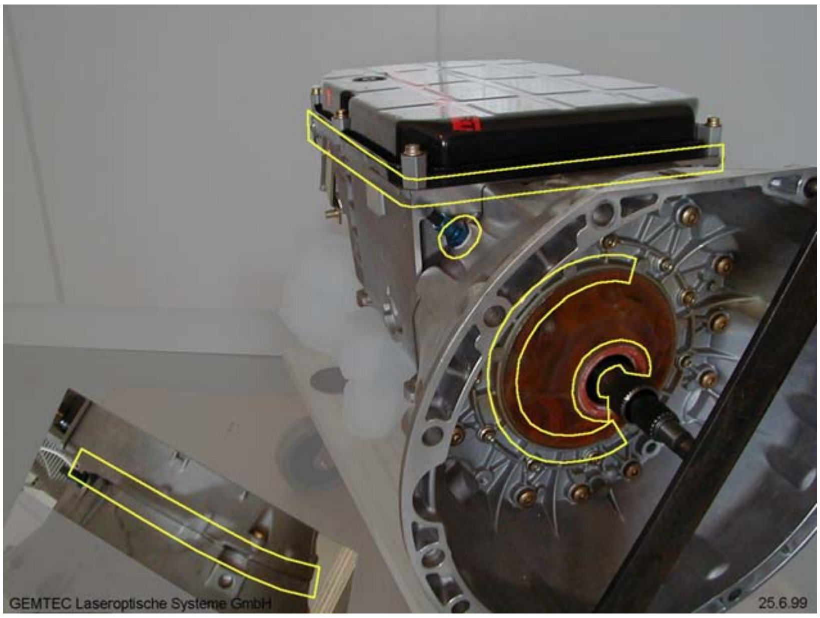


Illustration No. 19: STS 400 M / Scanning view No. 3

Thus large, complex objects, for example automotive engines, after their final assembly, as well as small parts produced in large numbers can reliably be tested for leaks. The fully automated procedure makes constantly low rejection rates possible. In contrast to the underwater method, the procedure is not influenced by the testing person. The system STS 400 M, therefore, is especially suited to industrial production and quality control.