Summary

Strain/stress sensors are important elements of the structural health monitoring (SHM) systems. SHM systems are used to monitor civil structures, aircrafts, and spacecrafts. Until now, strain gauges, fiber optic, piezoelectric and magnetic sensors have been used to strain monitoring. The idea of using microstrip resonators for this purpose has recently appeared.

There are a lot of problems in measuring deformation by microstrip sensors. A series of problems are resolved in this doctoral dissertation. A linear dependence of resonant frequency shifts as a function of strain for one direction of force has been reported in the literature. The most common, the sensor with a rectangular patch for deformation in two orthogonal directions was analysed. For basic resonance, the elongation along the patch main axis causes a decrease in the value of the resonant frequency. Whereas, the perpendicular (to main axis) elongation of the patch causes an increase of the resonant frequency value. Thus, it is evident that there is an indirect force direction in which there is no shift of resonant frequency - the sensor is insensitive to deformation. For this reason, this Ph.D. thesis proposes a method of testing deformation using a microstrip sensor when the direction of the force is unknown, or the direction and value of deformation measurement are necessary. For this purpose, a circular microstrip sensor was utilized. Directional strain characteristics for two resonance frequencies were proposed and determined. The obtained characteristics have a different character. As a result, the direction and value of deformation can be determined.

Furthermore, the sensitivity analysis of the transducers with rectangular patches of different resonance frequencies was performed. The main conclusion from the analysis is: the higher the resonant frequency of the sensor, the bigger the resonance frequency shifts occur due to the deformation. Taking into account these relationships, sensors should be designed for high resonant frequencies. However, the design of a specific measurement system must also consider its price. The Vector Network Analyser (VNA) is the most expensive component of the entire system. VNA prices highly depend on the range of measurement frequencies (the higher the maximum measurement frequency, the higher its price). So, in the first step, the required sensitivity for a specific application should be determined, and then an analyser that meets this requirement can be selected. Finally, the sensor whose resonant frequency is close to the upper limit of the VNA frequency range should be chosen.

In the case of a known direction of external force, the condition of the component by measuring one resonant frequency can be monitored. During studying of direction and the deformation value using the circular microstrip sensor, the problem of a big difference between the values of resonant frequencies has appeared. So, the first of them will be significantly distant from the maximum measurement frequency of the Vector Network Analyser, which results in lower accuracy in the strain measurement. Therefore, in this Ph.D. thesis, a sensor with two rectangular patches designed for different but similar resonant frequencies was proposed. The main axes of the resonators in the proposed sensor are placed perpendicular to each other. Thus, the measurement of strain in two orthogonal axes is made. The difference between the two operating frequencies is only 100 MHz. This enables similar sensitivity for both resonances.

In this work, the miniaturization of microstrip sensors was also considered. At first, the sensitivity of transducers made on laminates with different permittivity was evaluated. Furthermore, a transducer with a fractal resonator was tested. The conducted analysis showed that the dimensions of the sensor can be reduced without reducing the sensitivity by using laminate with high electric permittivity. In the case of using the fractal patch for the third iteration of the Sierpinski curve, an area of the sensor geometry that is four times smaller caused only twice-lower sensitivity. Thus, a better method for miniaturization of microstrip strain sensors is the utilization of the high permittivity laminate. The use of fractal patch can be used in combination with high electric permittivity laminate in the case when sensitivity requirements are lower and stress measurement is required on a very small area or strain value local measurement.

As part of this work, a measurement system was built. The system consisted of the microstrip strain sensor, the portable vector network analyser, and the computer. The computer was equipped with the measuring software developed in this work with implemented signal processing algorithms. The measurement system has been verified.

In the proposed doctoral dissertation, new geometries of microstrip transducers as well, as signal processing algorithms were developed. A dual resonance frequency shift study was also performed for directional evaluation of strain. These solutions improved the operational properties of microstrip strain sensors, like increasing reliability (elimination of the state in which for an unknown direction of mechanical excitation the transducer is not sensitive to deformation), reduction of geometric dimensions or more effective use of the measuring equipment. All this can have a positive impact on competitiveness and increase the area of application of this technology.