Measuring Strain Using Microwave Energy

A thesis submitted by

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Abstract

The measurement of force (or weight) is required in a great diversity of industries and applications. The wide range of force levels, force characteristics and required data has driven the development of many different technologies to meet these needs. Most of these technologies depend on the force (or weight) deforming an elastic load bearing member, with some form of transducer to convert the strain in the member to an electrical quantity. The selection of this transducer will depend heavily on the particular application. The range of major technologies are briefly reviewed and their limitations noted.

The research set out in this dissertation investigated an original transducer system that uses microwave energy to measure the strain in a loaded member, with the member forming an integral part of the transducer. The basic design principle involves a pair of cavities in the elastic member, one only which is subject to deformation under load, while both cavities share a common temperature profile. The cavities are caused to resonate by a microwave feedback exciter, and the difference frequency between the cavities is extracted. This difference frequency will carry information related to the strain in the loaded cavity, whilst discriminating the common mode dimensional changes due to expansion and contraction with temperature change.

The design of a prototype transducer system focused on three areas:

The mechanical design of a transducer which produced strain in the loaded cavity in one co-ordinate direction only, so as not to produce complex deformation of the cavity. In principle this would ensure good linearity between the applied load and the microwave resonant frequency change in the cavity. Further, the second cavity was arranged to
experience no strain when the first cavity was loaded, but both cavities were adjacent in a single block of metal to ensure a common temperature profile. This member was designed to meet all the normal requirements, specifically low creep, high fatigue life and good stress-strain linearity within Hooke’s law, but also had to be suitable for manufacture in a material having low resistivity to maintain high Q values in the cavity resonators. The readily available Alloy-380 brass was chosen.

Electromagnetic analysis was undertaken for both shallow cylinder and shallow square box cavities, and the methods of electrically coupling into each. The resonant frequency sensitivity to cavity deformation in different co-ordinate directions and modes of resonance was also analysed. The advantages and disadvantages of each, and the choice of a suitable cavity resonant frequency is discussed.

Microwave system design comprised a loop feedback type microwave oscillator using MMIC (monolithic microwave integrated circuit) devices as the active components. The phase and magnitude data for coupling between the cavity probes is detailed, and an analysis of the design procedure for the printed circuit board microstrip layout is described. The difference frequency between the two cavities was extracted using a microwave mixer, and its design is detailed including the local oscillator and the intermediate frequency amplifier.

Two aspects of performance verification of the design were undertaken. Firstly, resonator performance measurements were undertaken and analysed with respect to the performance of the microwave equipment available. Measurements revealed the characteristics of the coupling probes in the cavity, the performance of signal output coupling alternatives between the cavity and the effects of circuit shielding. The principal results were:

- Phase noise = -50 dBC/Hz (relative to carrier) at 1 kHz offset from carrier
- 3 dB bandwidth = 2 kHz
- Drift = -0.0055% of carrier / 5 minutes
- Centre Frequency (carrier) = 8.23 GHz
Secondly, the performance of the complete prototype transducer was measured. Apparatus to load the transducer was designed and constructed, and the output difference frequency between the two cavities monitored during progressive loading and unloading, and independent repetitions provided an assessment of repeatability. The results yielded a sensitivity of $4.84 \pm 0.05$ and $4.79 \pm 0.05$ kHz/kg wt (respectively), at least 99.9% linearity, and nil detectable hysteresis (i.e. less than the limits imposed by the measuring equipment).

It is concluded that the technique is feasible and proof-of-concept has been achieved, but there remain significant challenges before the technique would be commercially viable. Recommendations for further work are also outlined.
Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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