2004

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Libralato, Michele and Contarini, Andrea, "Impact Fatigue on Suction Valve Reed: New Experimental Approach" (2004). *International Compressor Engineering Conference.* Paper 1717.
https://docs.lib.purdue.edu/icec/1717

IMPACT FATIGUE ON SUCTION VALVE REED: NEW EXPERIMENTAL APPROACH

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ABSTRACT

This paper summarises a methodology developed to study the impact fatigue issue on the suction valve reed of refrigeration compressors by an experimental way. To perform it a special test-bench able to cause the tip breakage of the valve has been built. It is able to test more specimens by controlling the impact velocity of the reed, and is based on the use of air flows making the valve flutter. The results of these tests can be compared with the impact velocities achievable on the appliance in order to verify the reliability of the valve.

1. INTRODUCTION

The elimination of the suction reed stop in the household refrigeration compressors in the last years determined the rising of the failures on the tip of the reed due to impact fatigue, because of the increase of the impact velocities for the valve. In the past some suppliers of steel for valves (e.g. Sandvik, Uddeholms) performed studies to understand and prevent the issue, mainly to verify the resistance of their material. For this purpose they realised special experimental sets-up able to induce the failure of special specimens forced to impact on a seat at a fixed and known velocity. The main results of their activities give some information about the material, indicating the stainless steel more resistant than carbon steel, and about the geometry, indicating the overhang of the reed on the seat in favour of safety, as the width of the seat.

Nevertheless the specimens used were quite different for shape and dimension from the reeds used in household refrigeration compressors of small size, and the results were not directly applicable to the real pieces in production. A step forward is to verify directly the impact fatigue resistance of the reed coupled with its own valve plate seat, as it comes out from the production.

In order to have a flexible system able to test all the combinations of reeds and valve plates drawn from real designs and processes, in ACC Compressors a special test bench, where every kit reed-valve plate can be positioned, has been built. In this test-bench the reed is forced to flutter and impact on the seat by opposite pulsating air flows acting with a difference of phase. Besides, in order to have a fit statistic base to evaluate the impact fatigue limit in a reasonable short time, more places to test more reeds simultaneously have been developed in the system.

Once the impact fatigue limit of the reed in terms of impact velocity for the desired failure probability is evaluated by the test bench, the data can be compared with the maximum impact velocity achieved by the valve on the compressor working on the cabinet at the most critical conditions.

2. TEST-BENCH FEATURES

The test bench used for impact fatigue is based on two opposite pulsating air flows acting with a difference of phase, in such a way as one makes the reed open, the other forces the valve to close and impact on its seat. The reed is coupled with its own valve plate and jointed at the root by its gasket as in the compressor situation. In this way the real mechanical properties in terms of stiffness and natural frequency are reproduced in the system.
This kind of air flow pulsates with a high frequency not to have the opposition of the elastic reaction force of the valve, whose natural frequency is quite high (about 250-300 Hz). The use of the second flow forcing the valve to close is helpful to make the valve flutter with a higher frequency than the natural one, which favourites the increase of impact velocities. The purpose is achievable if the frequency of pulsating air flows can overcome it. The system set can achieve 1000 Hz for air pulsations.
Naturally, the two opposite flows must have a precise and controlled difference of phase to avoid the overlay and the balance of the opposite loads on the reed. In the system the difference of the phase is carried out and kept by an electronic control. It can be set before starting or during the test to modify the velocity.
The other parameters influencing the impact velocity are the pressure of the air jet and the flow rate which determine the maximum lift of the valve. In order to have a low consumption of air from the air supplier line the pressures and the flow rate are set at a low value, while the frequency at a high value (higher than the natural frequency). This set of parameters permits to have a steady behaviour of the system and keep a constant value of the impact velocity.
The velocity is indirectly measured and monitored by a proximity transducer: it is the derivative of the displacement signal measured. The sampling frequency of the transducer is very high (over than 100 kHz) and this allows to have a correct value of the velocity by the derivative; in figure 2.1 a chart with the reed velocity (m/s) versus time (ms) on the bench is shown. The positive sign for the velocity value corresponds to the closing period of the valve. The wide range of the flat course on the chart is due to the small range of displacements (few tenths of mm) that the proximity transducer can measure before achieving the saturation.

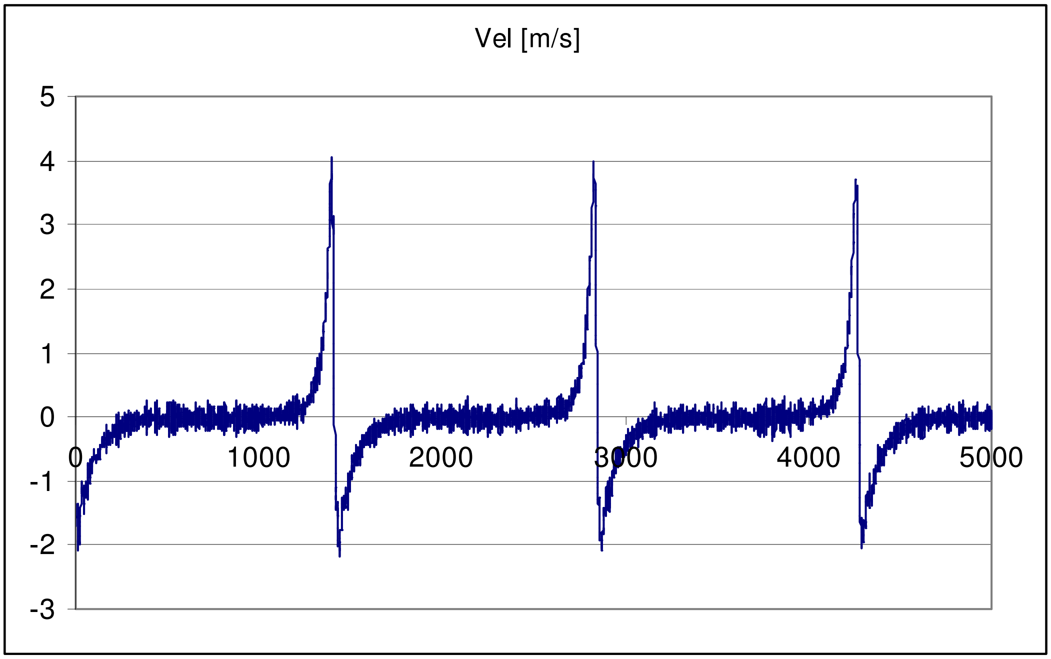

Figure 2.1: Instantaneous impact velocity

In the figure 2.2 and 2.3 two photos of a valve before and after the tip breakage during a test are illustrated.

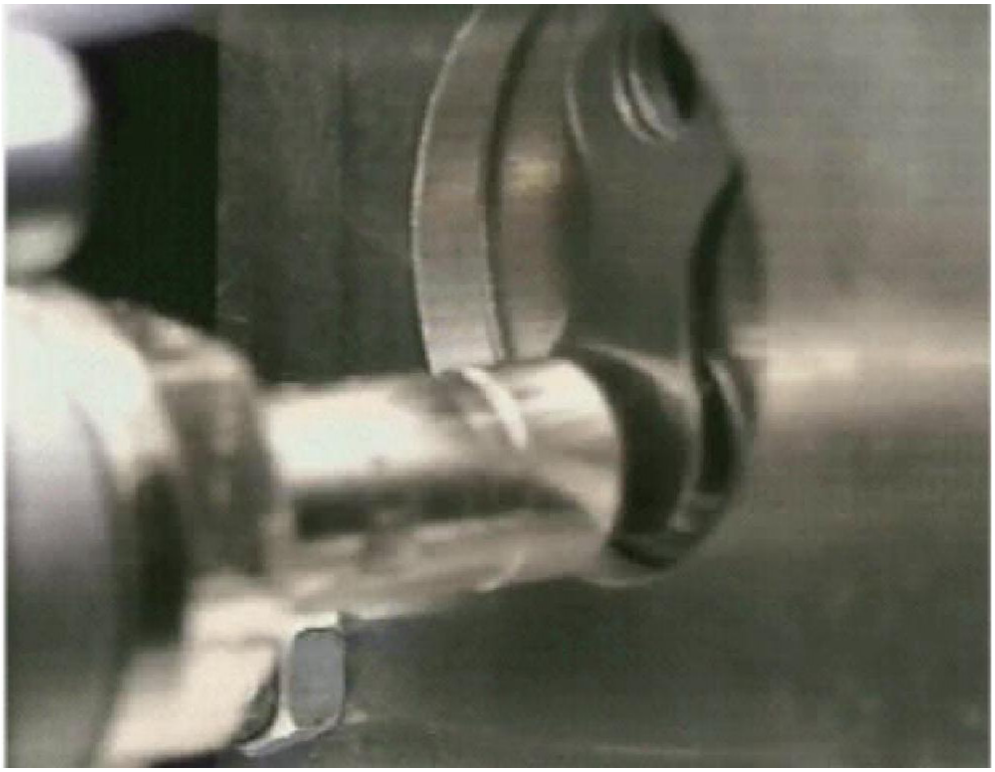

Figure 2.2: valve before failure

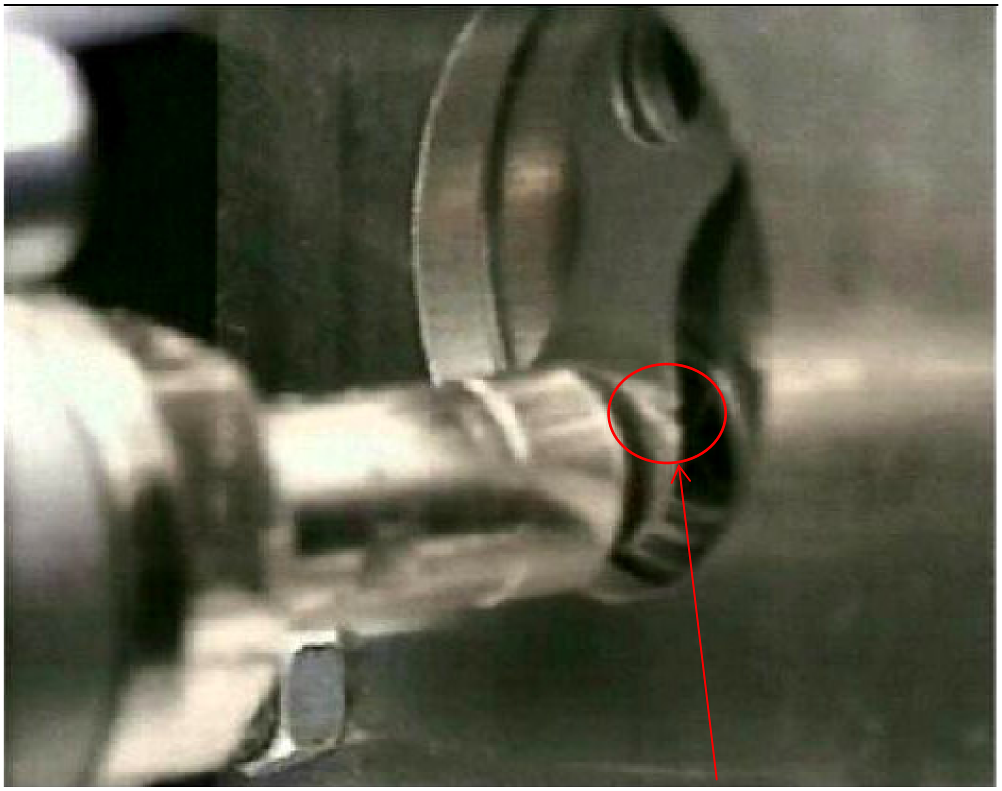

Figure 2.3: valve at a high lift after failure

3. FIRST RESULTS

Some kinds of different designs for valve plate-valve reed have been tested, with different material both for valve plate and reed. Which is interesting, the critical range of impact velocity for all the reeds is from 4 to 6 m/s (figure 3.1). The values have been obtained testing a certain number of pieces (enough to have a significant statistic base) for each valve design per each impact velocity (3.5, 4, 5 m/s). As regard to the high surviving probabilities the number of pieces has to be increased in order to increase the confidence. Besides, these values are not completely representative of the real situation in the compressor, cause of the oil missing; the presence of oil reduces the impact stress at a certain velocity.
To have more information about the influence of the different parameters on the impact fatigue, a sort of DOE should be built taking into account overhang, edge finishing, material, width of the seat, hardness of the seat. At present, a comparison among different valves in the current production and some tests varying the hardness of the seat have been carried out. The figures 3.1, 3.2 summarise these results. Figure 3.2 shows the curve of surviving probability percentage versus impact velocity of one reed design tested with valve plate of standard steel material (about HV 100) and nitrated valve plate (HV 500). The hardness of the seat seems to decrease the impact fatigue resistance when impact velocity increases.

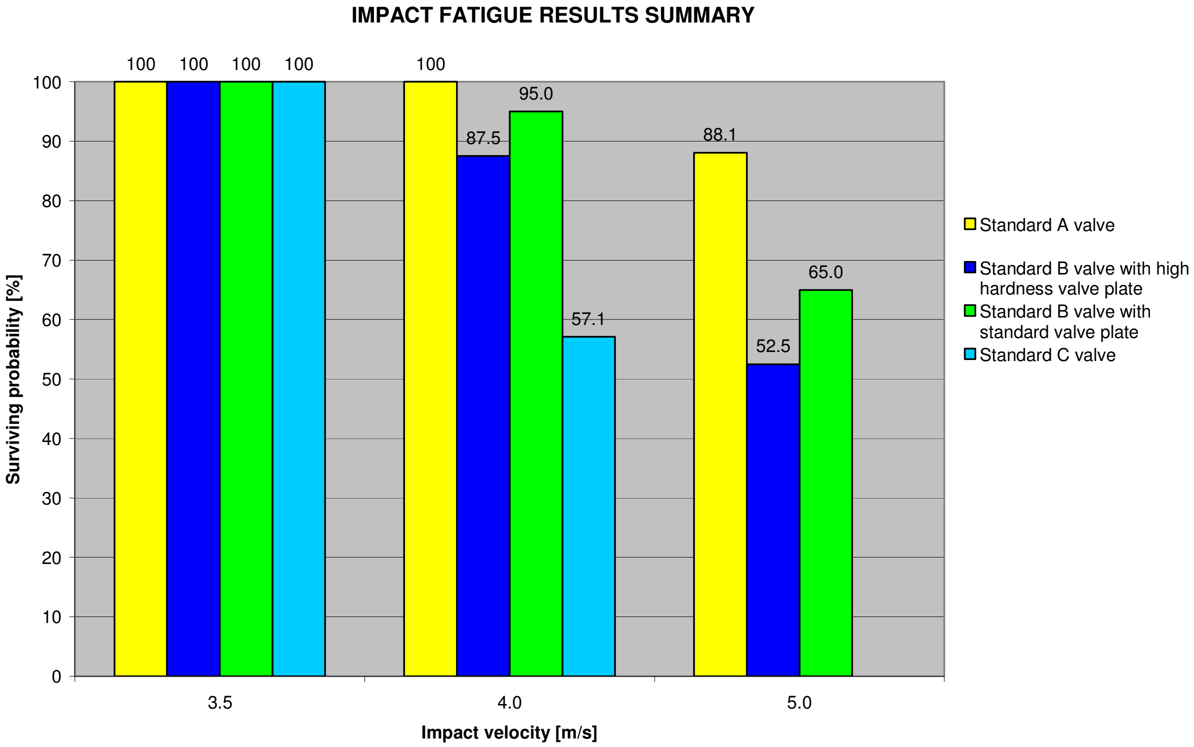

Figure 3.1

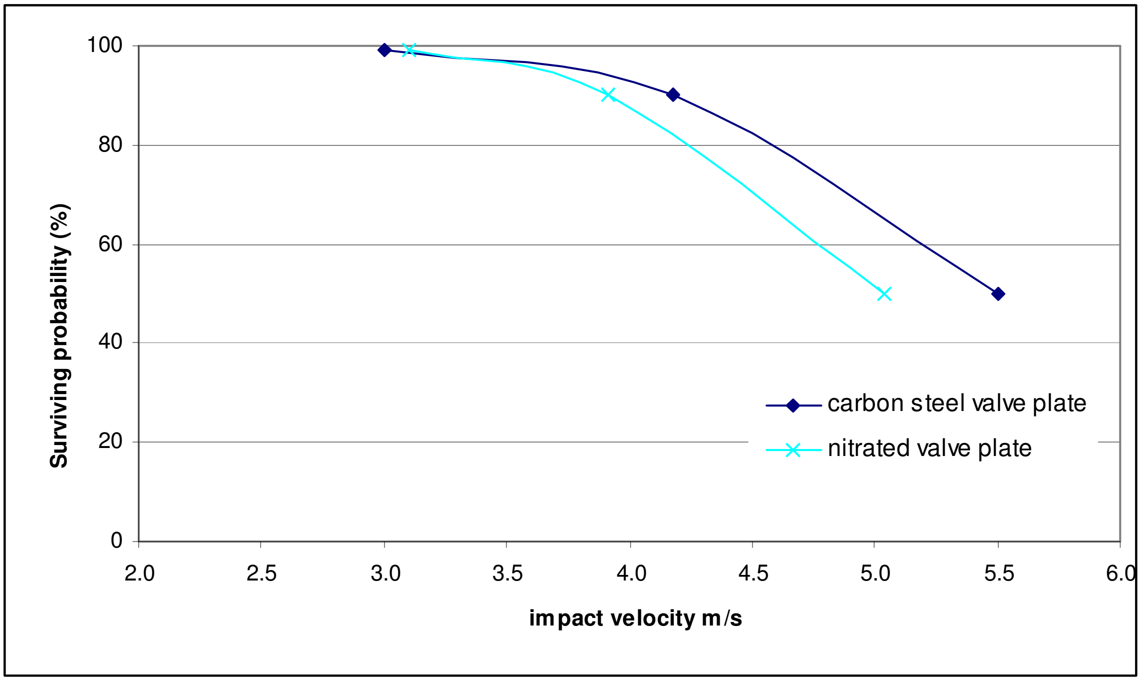

Figure 3.2: surviving probability vs impact velocity

In the figures 3.3, 3.4 the displacement (lift) and the impact velocity of the C type suction reed (chart in the figure 3.1) from measurements in a compressor working in a refrigerator at the most severe thermodynamic conditions are reported. The measurements have been performed by the same type of proximity probe used for test-bench.

The thermodynamic conditions correspond to a pull-down with a great amount of load packs in front of the evaporator. The maximum lift and impact velocity of the valve happen during the transient period at the beginning of the test. In the 3D chart of figure 3.3 a sequence of valve motion diagrams per compression cycle sampled for a short time range is shown.

In the figure 3.4 the maximum impact velocity during one compression cycle, achieved at the end of the second flutter, is 2.4 m/s. This value compared to the ones with very high surviving probability drawn from the test-bench in chart 3.1, also considering the presence of oil in the compressor increasing safety, indicates that the standard valve C is in safe condition for impact fatigue on that cabinet.

This is an example of a new methodology to be introduced to verify a suction reed for impact fatigue.

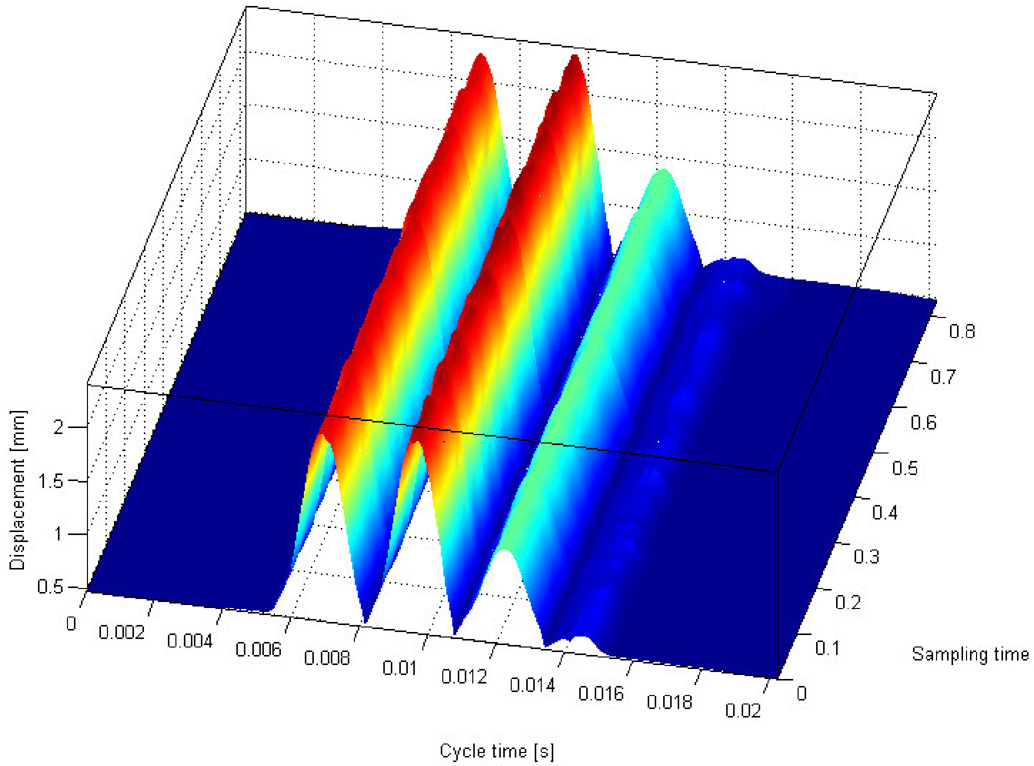

Figure 3.3: displacement of the reed (mm) vs time inside 1 cycle and sampling time

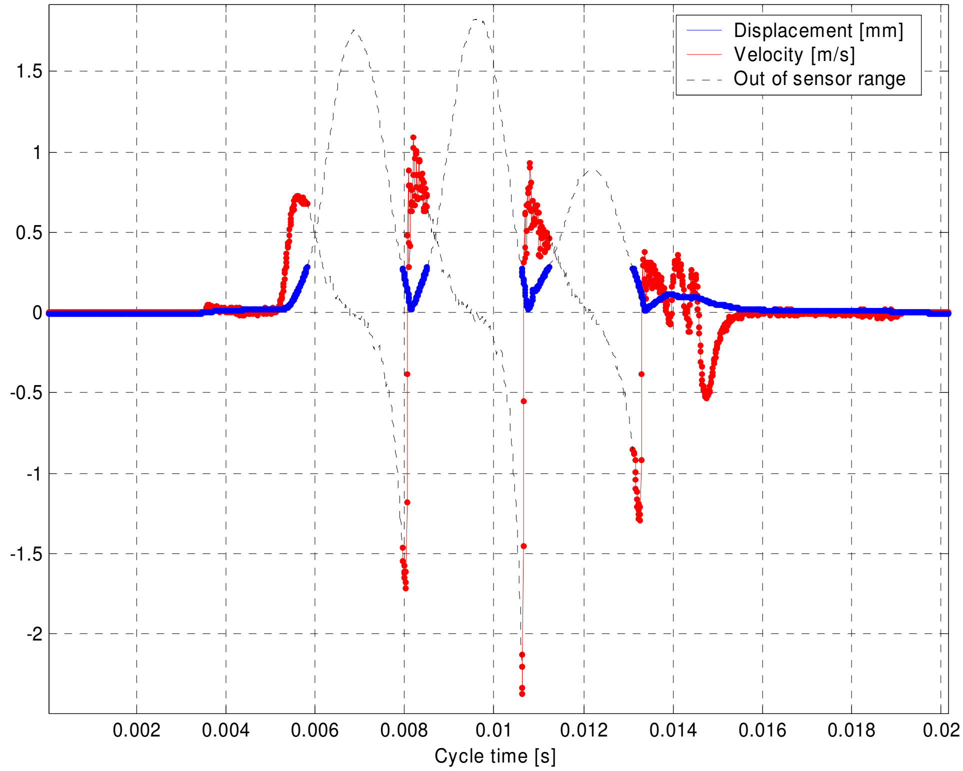

Figure 3.4: displacement of the reed (mm) and impact velocity (m/s) vs cycle time

4. CONCLUSIONS

The methodology to verify the reliability of the suction reed for impact fatigue summarised in this paper can give a good confidence to prevent the impact fatigue issue achieving a robust design without adopting solutions limiting the compressor performances.
A further step to improve this methodology can be the introduction of the oil effect in the evaluation of the impact fatigue resistance of the reed. This could be implemented in the equipment of the test-bench in the future.

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ACKNOWLEDGEMENT

We would like to thank Mr Antonio Cerabolini, ACC Innovation Laboratory, who has given an important contribution to the achievement of the reported results.