COILABILITY TESTING FOR CARBON STEEL WIRE

by M.P.Hayes

'You cannot truly say that you understand something unless you are able to measure something about it' - so said the eminent Scottish scientist, Lord Kelvin, 100 years ago. This philosophy was in the mind of the author when he concluded, in his paper (1) given at the WAI European Conference in Berlin in 1993, that a lathe coiling test showed potential for development as a standard test for evaluating coilability of spring wire. Since 1993 considerable development work has been undertaken on the lathe coiling test, which is now known as the FRACMAT test. For the first time this test measures parameters that will reliably classify spring wires in terms of coilability - or springmaking tolerance control.

Background Information

The purpose of CRAFT-01, a two year European cooperative research project, was to identify the carbon steel wire quality parameters that correlated with inconsistent spring manufacturing tolerance control. In this respect, the project was partially successful, identifying high and variable suspended corkscrew set, and high proof stress / UTS ratios, associated with strain age hardening, as parameters most likely to be associated with springmaking tolerance control problems. However, these reasons only explained about 40% of the instances of inconsistent spring dimensions.

Hence the investigation of spring tolerance control continued, but was looked at from another point of view. If the wire quality parameters associated with problem wires could not be reliably identified, then could a test be developed that would reliably sort good from poor coilability wire?

To be successful, such a test would have to be capable of reliably and consistently sorting good wire from poor, even if it did not reveal precisely why the wire was good, poor or average.

The lathe coiling test, proposed in CRAFT-01, has been the basis for the development of a standard coilability test for spring wires, now known as the FRACMAT test. The knowledge gained in CRAFT-01 about the importance of elastic / plastic properties and residual stresses in spring wires was utilised, as was IST's experience that in some circumstances, the frictional properties of wire surfaces can be important.

Development of the FRACMAT test

Springmakers know that it is large index springs that cause the greatest tolerance control problems, largely due to the relatively small amount of plastic deformation required to achieve the required dimensions. Hence the FRACMAT test exaggerates this effect by lathe coiling a 'test spring' with an index of about 20-30, with a pitch of only 1.5 times the wire diameter. Springmakers also know that tolerance control problems can come and go through a coil, and so a long length of wire has to be tested. Approximately 500 turns per 'test spring' has been found to be sufficient, this representing about 35 metres of wire - indeed as confidence is developed in this test method, there may well be scope for reducing the 'test spring' turns to 200.

After the 'test spring' has been lathe coiled around a mandrel, it has to be allowed to spring back elastically after coiling, so that the 'test spring' achieves its unrestrained shape - it is in this state that the coiling ratio of 20-30 is realised. Now this long slinky 'test spring' has to be carefully measured. To do this it is extended (without causing any plastic deformation of course) so that all the coils separate - some parts of the spring often become close coiled when released from the mandrel - and the 'test spring' is measured. It is the gap, or pitch, between each coil of the 'test spring' that is measured using a laser, the results then being automatically corrected for the extension.

It wouldn't be necessary to use a laser to distinguish between a good wire and a poor one, as illustrated in Figure 1, but the FRACMAT test enables accurate classification of the coiling performance of wires both in terms of a statistical descriptor (variability) and a chaotic descriptor (inconsistency) as shown in Figure 2. The most advanced methods of mathematical Chaos Theory (2) have been employed to produce this very accurate classification of the coiling properties of spring wire. The laser measuring results are stored and analysed directly by a computer incorporated into the test machine, so that results of a FRACMAT test can be seen immediately in a graphical easy-to-understand format, and can be compared directly with previous results for similar wires. It will be understood that the development of the software to enable this immediate analysis and classification of spring wires has taken some time, but it is now fully tried, tested and proven for successful classification of wire coilability by the FRACMAT test.

During the course of the development of this machine, it was realised, particularly for coated carbon steel and austenitic stainless steel wires, that further information could and should be gathered about the frictional properties of the wire surfaces. In order to undertake lathe coiling of a spring, it is necessary to apply some back tension to the wire to keep it in contact with the mandrel on which it is being coiled. Development work showed this could be applied by pulling the wire through two carbide blocks, to which a load equivalent to about 15% Rm is applied. A load cell was attached to the friction blocks so that the surface frictional data could be continuously monitored during the lathe coiling and the friction data is then analysed using the same mathematical techniques as those used for analysing the pitch data. For some wire products, within and outside the spring industry, this device for measuring sequential frictional properties is of more interest than the pitch measuring capability.

Description of the FRACMAT test

A photograph of IST 's FRACMAT tester is shown as Figure 3, the essential components of which are

- the lathe coiling device - the speed of which is controlled, via the computer, by two servo motors to a synchronised accuracy of better than 1%

- the laser measuring device for measuring the sequential pitches of the test spring, as shown in Figure 4.

- the friction device for measuring the sequential surface frictional properties of wires, as shown in Figure 5.

The FRACMAT test is currently capable of testing round wires in the size ranges 0.25-2.40mm.

Scope of Applicability of the FRACMAT test

As with all new and innovative test procedures there is a need to build up customer confidence that the test is reliable, repeatable and cost effective. The first stage in building up such confidence was IST 's invitation to its members to submit samples for test, the results of which tests were reported in December 1995 (3).

Since that data, individual client's and IST 's confidence in the test has been built up by commercial testing of a very wide range of carbon steel spring wires (with and without coating), stainless steel spring wires, copper and nickel alloy wire and drawn mild steel wires. Client confidentiality has to be respected when reporting these results, but a number of success stories can be reported here in the form of case histories.

- A US spring manufacturer reported significant differences between two coils of carbon steel spring wire, both of which had been re-tested to make sure they met specification. FRACMAT testing of samples indicated that the two wires (from different vendors) were so similar that they could be identical. The springmaker was astonished to receive this result, but traced the histories of both wires back to the same cast of steel (made in the UK as it happens) and wire drawer. It was then acknowledged that the second wire that gave problems was due to a fault, found some days later, on the spring coiling machine. This case history is typical of about 30% of all investigations - that the coiling problem lies with the coiling machine rather than with the wire. Unfortunately, that means the remaining 70% of problems are down to the wire suppliers.

- A stainless steel wire drawer in the Far East was losing orders because a competitors wire was said to give better tolerance control than their wire when manufacturing large index torsion springs. FRACMAT test results showed that both suppliers wires gave satisfactory results. Armed with these results, confidence was renewed and IST 's client was able to win back their market share.

- A UK spring manufacturer reported an unacceptably high reject rate when coiling long compression springs. The rejects were for springs which were out of tolerance in length. FRACMAT tests showed that the wire was very consistent, but had a periodic problem in the pitch data. This periodicity was traced accurately to a frequency of twice per original bundle diameter, and was attributed to a kink in the wire caused by excessively tight bindings on the bundle.

- A European wire drawer supplied seven wire samples to his client and to IST for simultaneous reporting of coilability as measured by a spring manufacturer and by FRACMAT. The spring manufacturer and IST both reported that two of the wires were conspicuously better than all the others. The wire drawer was very impressed by the correlation, but was not so well pleased that the most expensive process route gave the best results.

Several more case histories could be related, but suffice it to say, that none of IST 's customers have had reason to dispute their FRACMAT test results. Indeed, the NAMAS authorities have agreed to include the FRACMAT test within IST 's accredited scope.

To build up confidence in this test in Europe, and to evaluate the full scope of its applicability, a collaborative project between three independent wire producers and three spring manufacturers will start in the Autumn of 1997. This work will be part funded by the European Commission's Standards, Measurement and Testing Programme under proposal number 2258, and will involve manufacturers from Belgium, Netherlands, Austria, France and UK. If successful, this project will submit a description of the FRACMAT test to the CEN committee responsible for spring wire specifications so that the committee can decide whether to include this test as an optional test in the appendix of those specifications.

FRACMAT Results

Earlier in this paper, it was argued that FRACMAT results are easy to understand and yet use is made of the very advanced methods of mathematical Chaos Theory. This may seem to be a paradox, but it will now be illustrated how to interpret these results by looking at a series of tests carried out on various 0.71mm diameter wires.

Wire A is a drawn carbon spring steel that has a little variability in its pitch results, but is very consistent as shown in Figure 6. Wire 1 is also a drawn carbon steel that has a little variability, but also a little inconsistency, as shown in Figure 7.

Wires 2 and 3 are both drawn 302 type stainless steel. Wire 2 is both variable and inconsistent in its pitch results - Figure 8. The inconsistency is mainly attributable to a regularly occurring feature at once per bundle diameter, as shown by the power spectrum - Figure 9. However the variability cannot be attributable to friction variations - Figure 10. On the other hand wire 3, which is also variable and inconsistent, but not so bad as wire 2 - see Figure 11, and note the different left hand scale compared to Figure 8, has variable and inconsistent friction properties, as shown in Figure 12.

Wire 4 is pre-galvanised carbon spring steel, and is both variable and inconsistent, Figure 13. Often problems of poor coilability in pre-galvanised wire are associated with variable friction, but in this instance the friction plot showed very little variability.

The results for these five 0.71mm diameter spring wires can be summarised on the classification diagram, shown as Figure 14. It must be emphasised here that all these wires were coilable, and this is reflected in the fact that none were classified as very poor, but clearly spring manufacturers would not have been pleased to receive wires 2, 3 or 4. In use for a tight tolerance spring, wires 2, 3 and 4 would all have given a high proportion of scrap out-of-tolerance springs. The FRACMAT test has shed light on some of the reasons for problems encountered with some of these wires. However, the reason for poor performance has not been identified for all the wires. FRACMAT is a test for measuring coiling performance, and will not always be a good diagnostic tool for solving the causes of the problems.

Conclusion

The FRACMAT test enables the reliable classification of the coiling and/or forming performance of a wide range of wire qualities. The full scope of applicability of the test will be established in the forthcoming European research project, but all investigations carried out to date have given results that have helped manufacturers to come to a better understanding of coilability. Incorporation of this test into the appendix of a number of international wire specifications is seen as the next logical step.

Acknowledgement

The help of my colleagues at IST, Len Reynolds and Iain Fielden, in preparing this paper is gratefully acknowledged.

References

1) M.P.Hayes, 'Wire quality and its effect upon carbon steel spring manufacturing tolerances' WAI European Conference, Berlin 1993 and Wire Journal International Dec '93, pp 74-77.

2) M.Muldoon, M.Nicol, L.F.Reynolds and I.N.Stewart, 'Chaos Theory in quality control of spring wire' - Part 1, Wire Industry, June '95, pp 309-311 and Parts 2 and 3, Wire Industry, Sept '95 pp 491-495.

3) L.F.Reynolds, I.N.Stewart et al, 'The FRACMAT test for coilability: a new concept in wire testing' Wire Industry, Dec '95, pp 669-673.

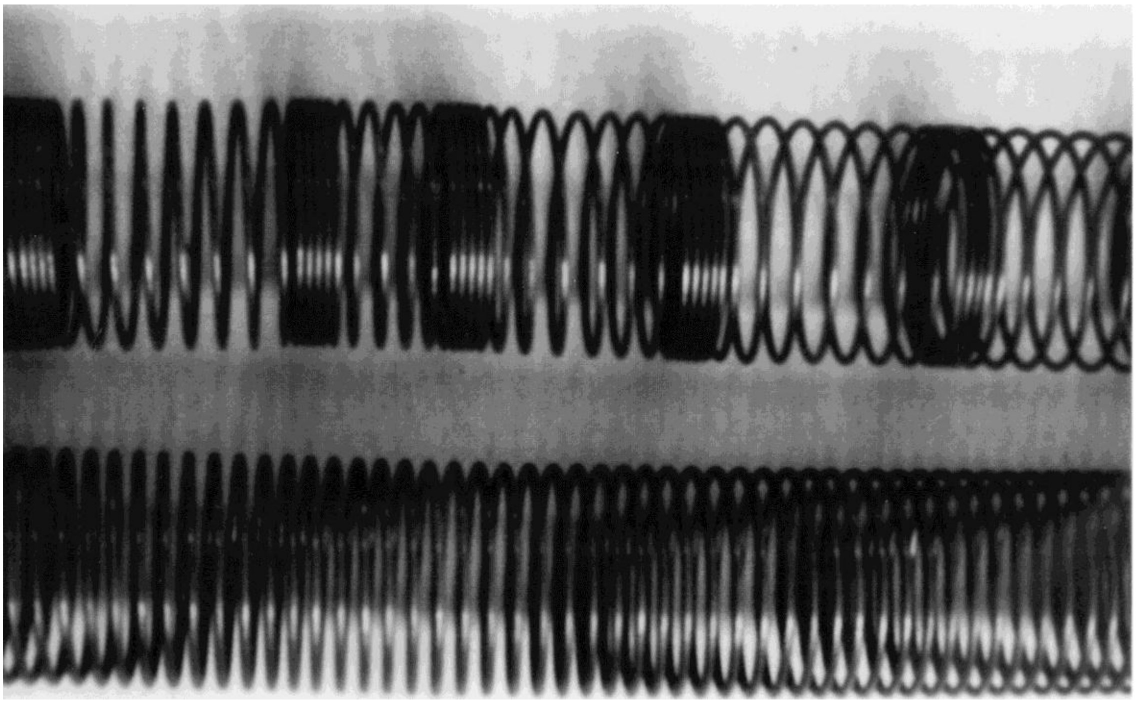

Figure 1 Photograph illustrating the typical test springs produced on the FRACMAT test.

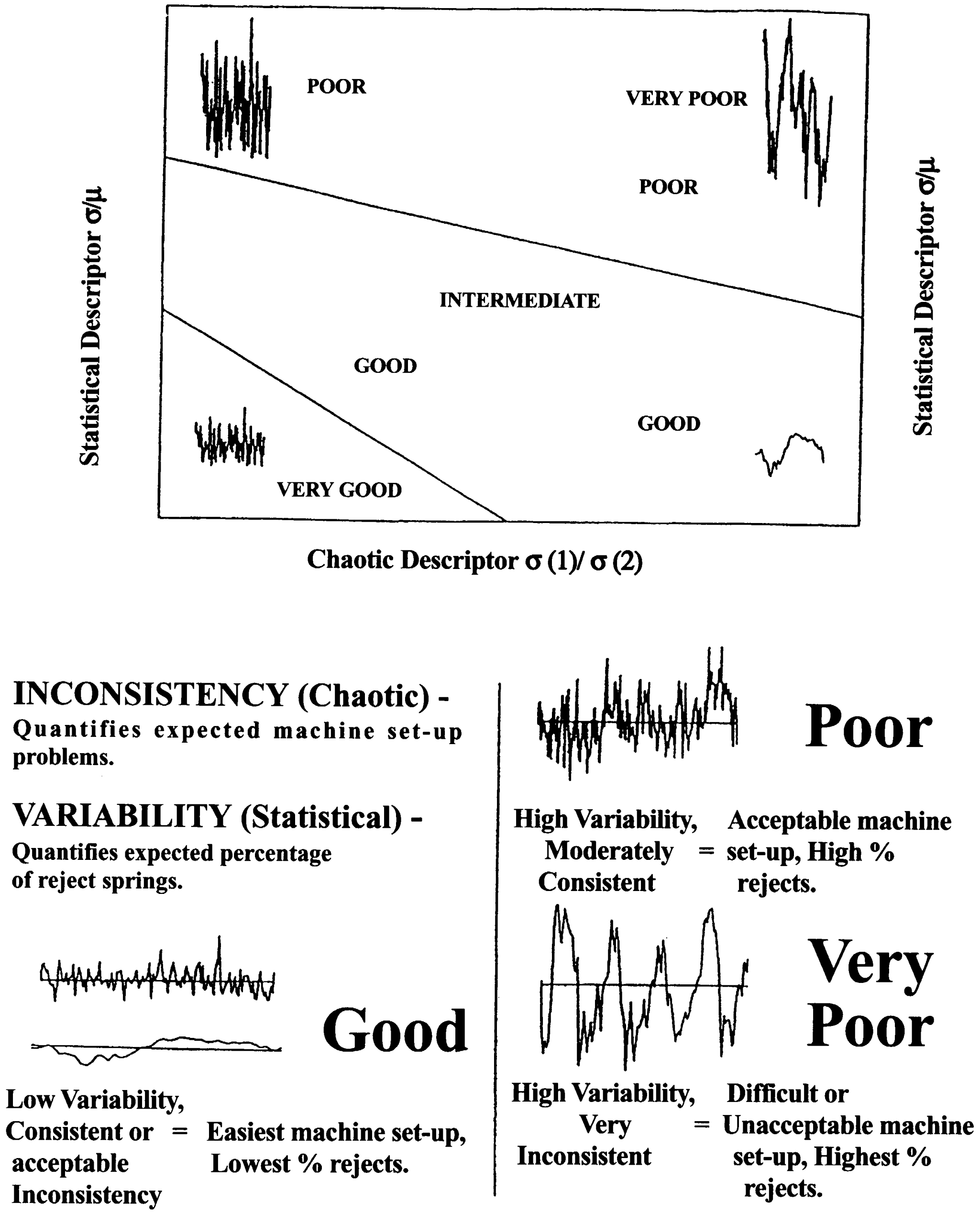

Figure 2 FRACMAT classification diagram characterising wire coilability


Figure 3 Photograph of a FRACMAT machine
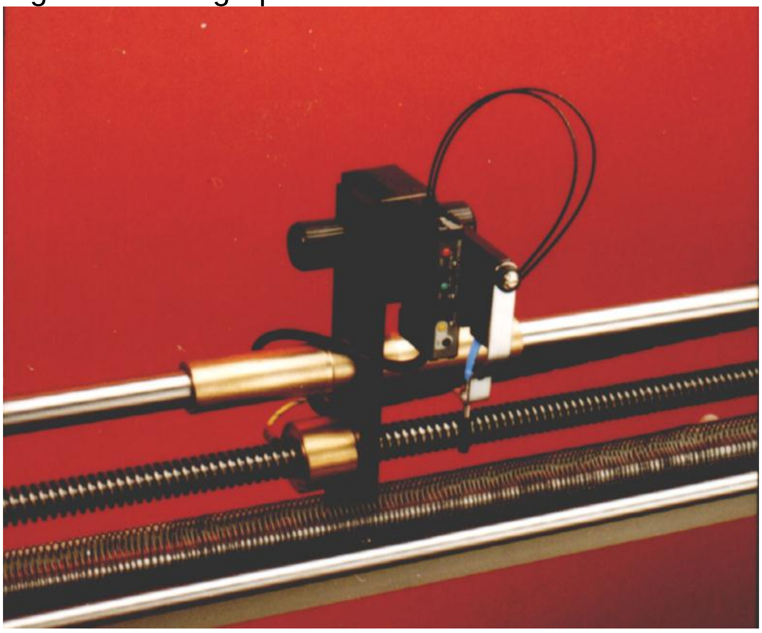
Figure 4 The laser scanner

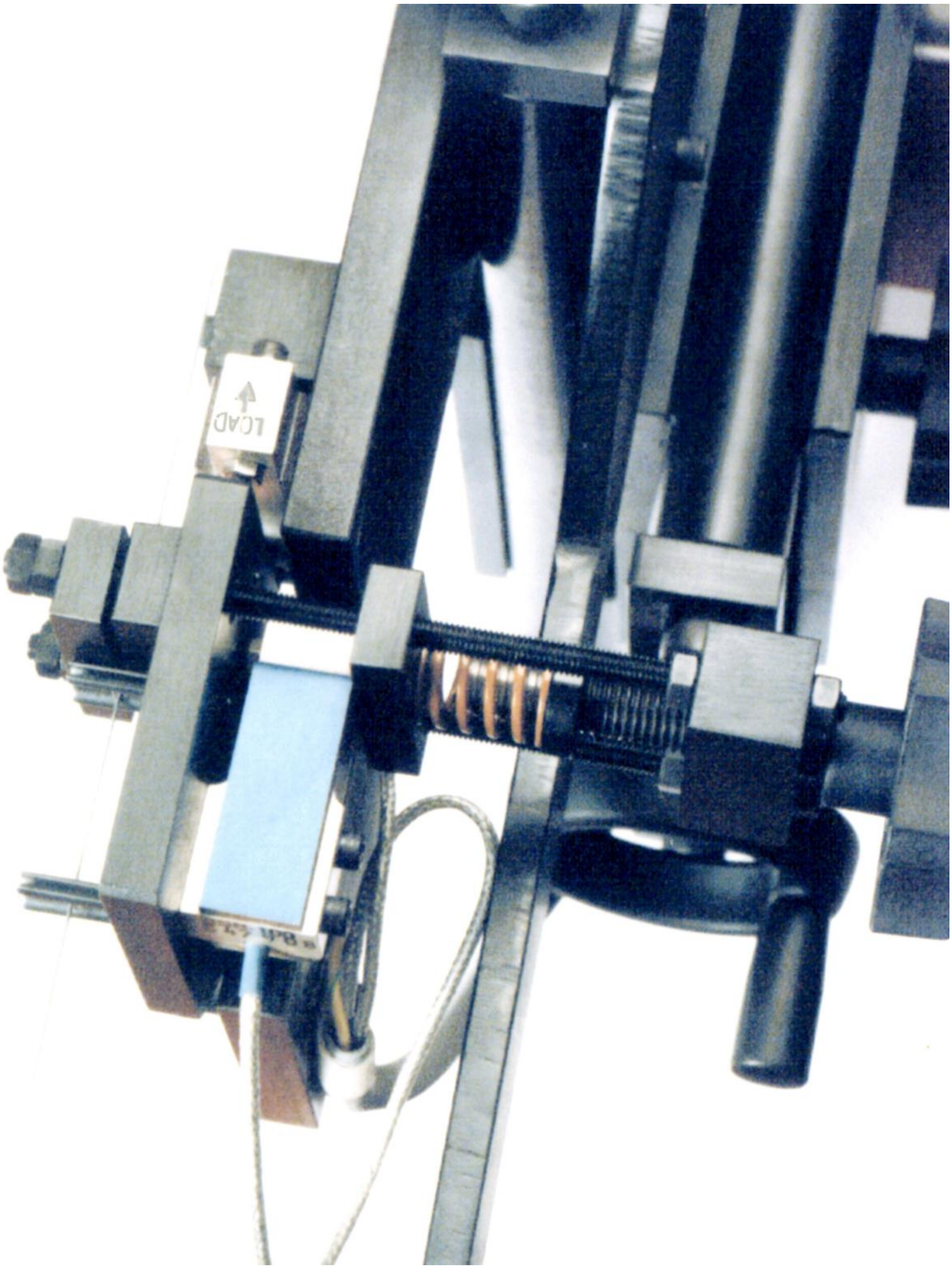

Figure 5 The friction measuring device

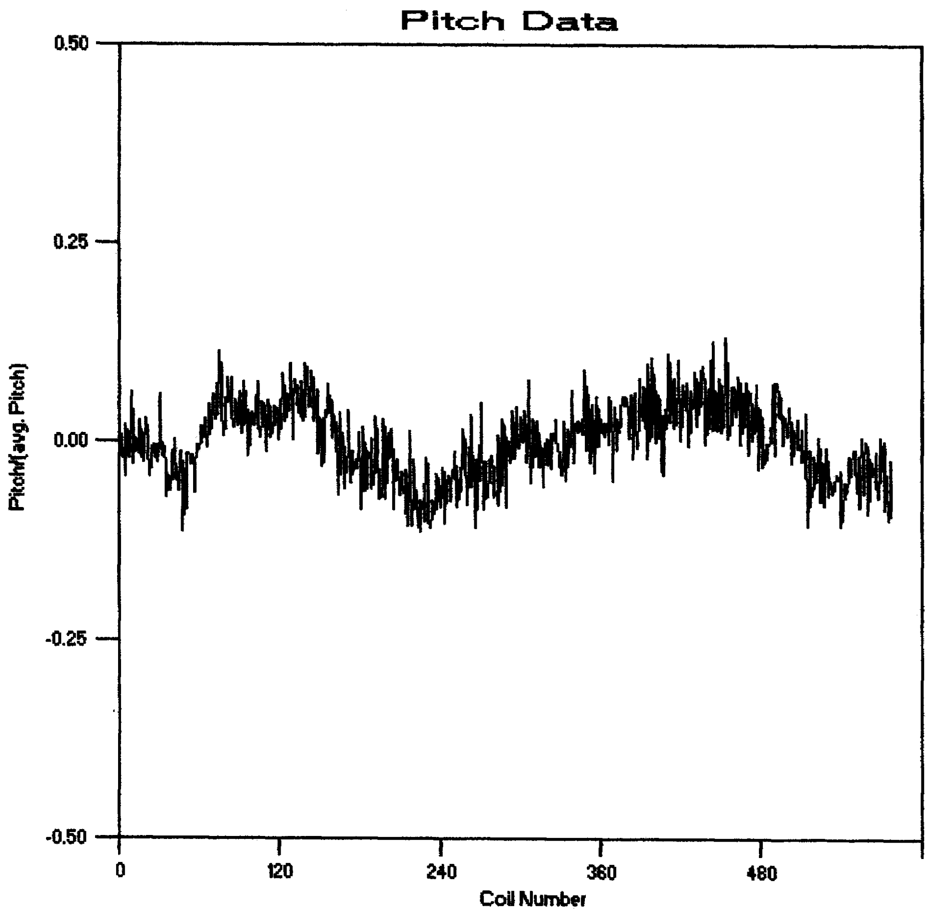

Figure 6 0.71mm drawn carbon steel, wire A

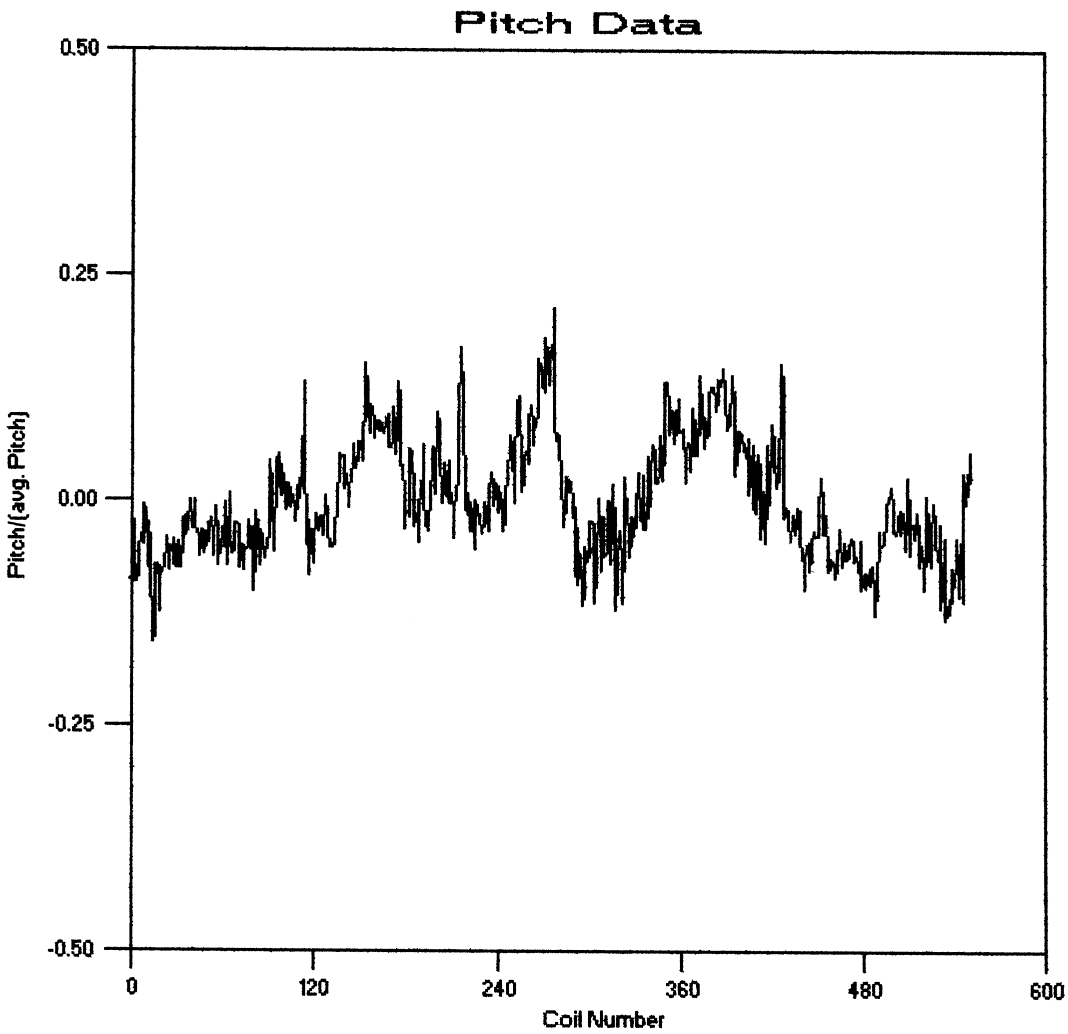

Figure 7 0.71mm drawn carbon steel, wire 1

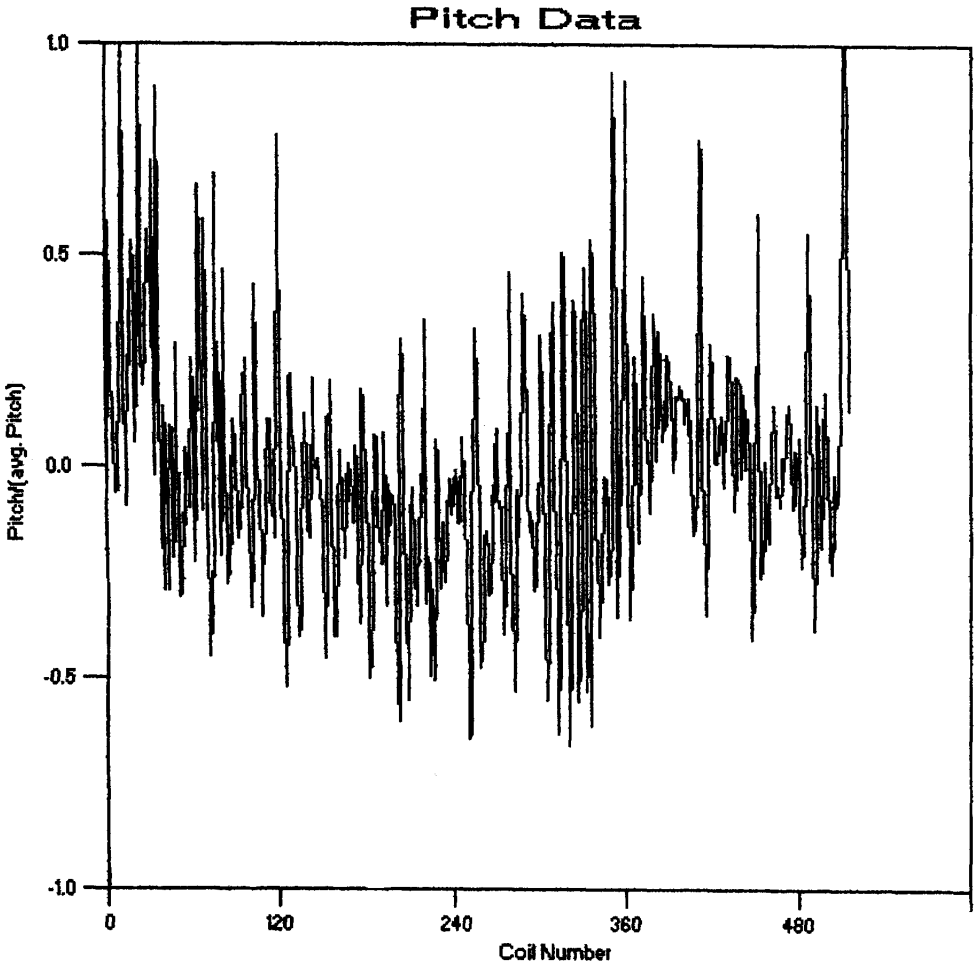

Figure 8 0.71mm 302 type stainless steel, wire 2

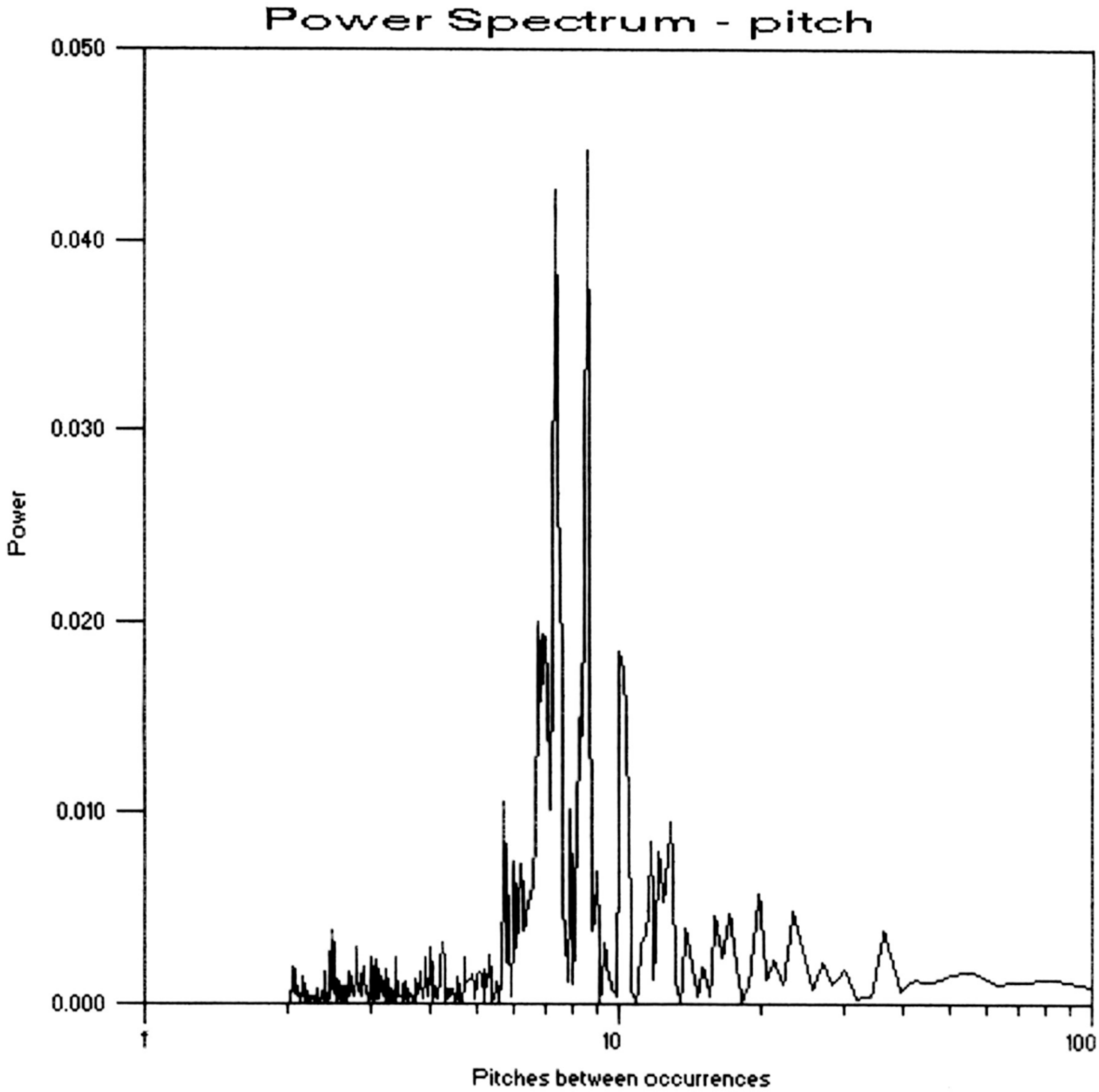

Figure 9 0.71mm 302 type stainless steel, wire 2

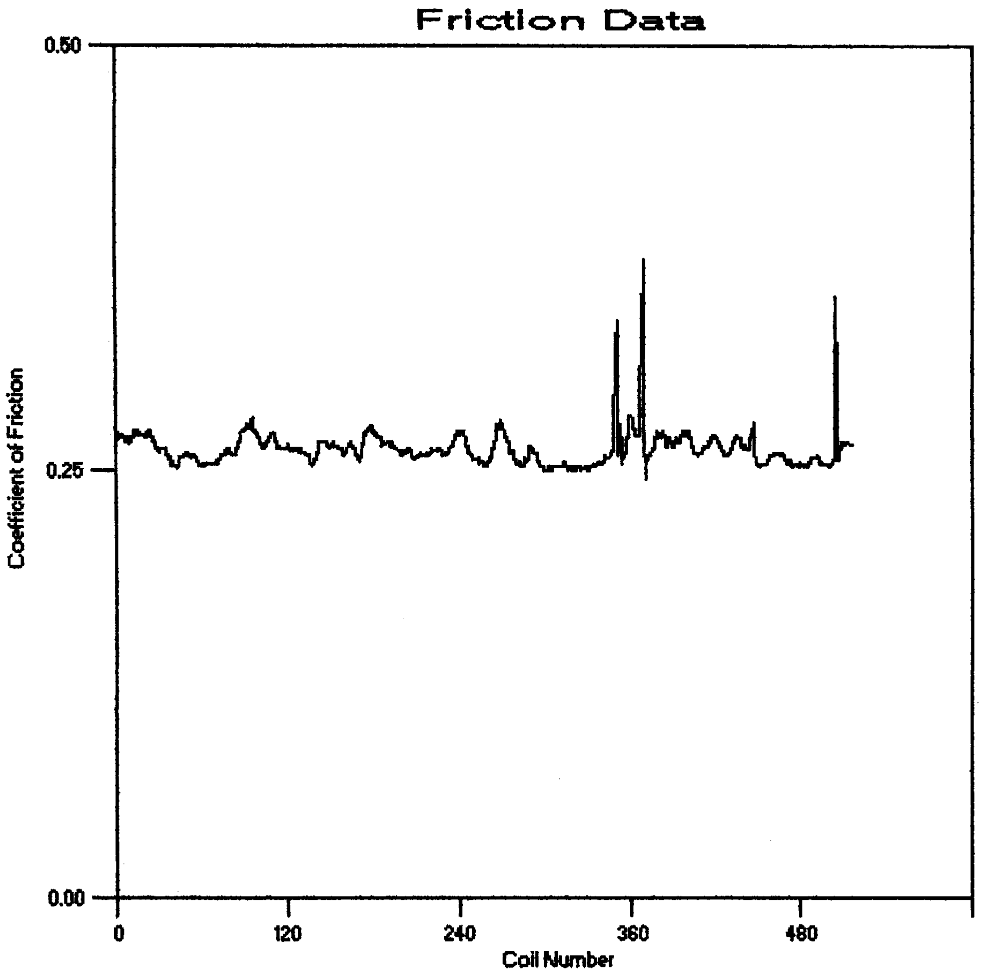

Figure 10 0.71mm 302 type stainless steel, wire 2

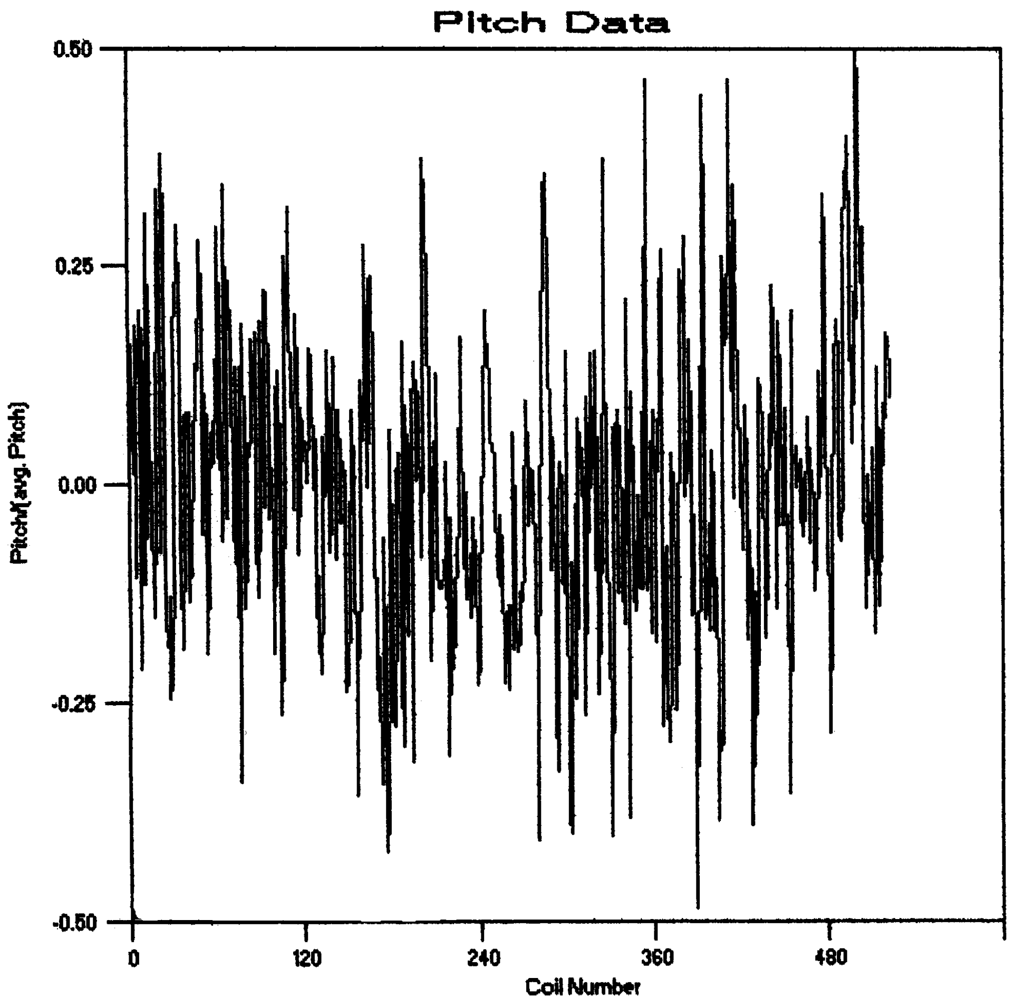

Figure 11 0.71mm 302 type stainless steel, wire 3

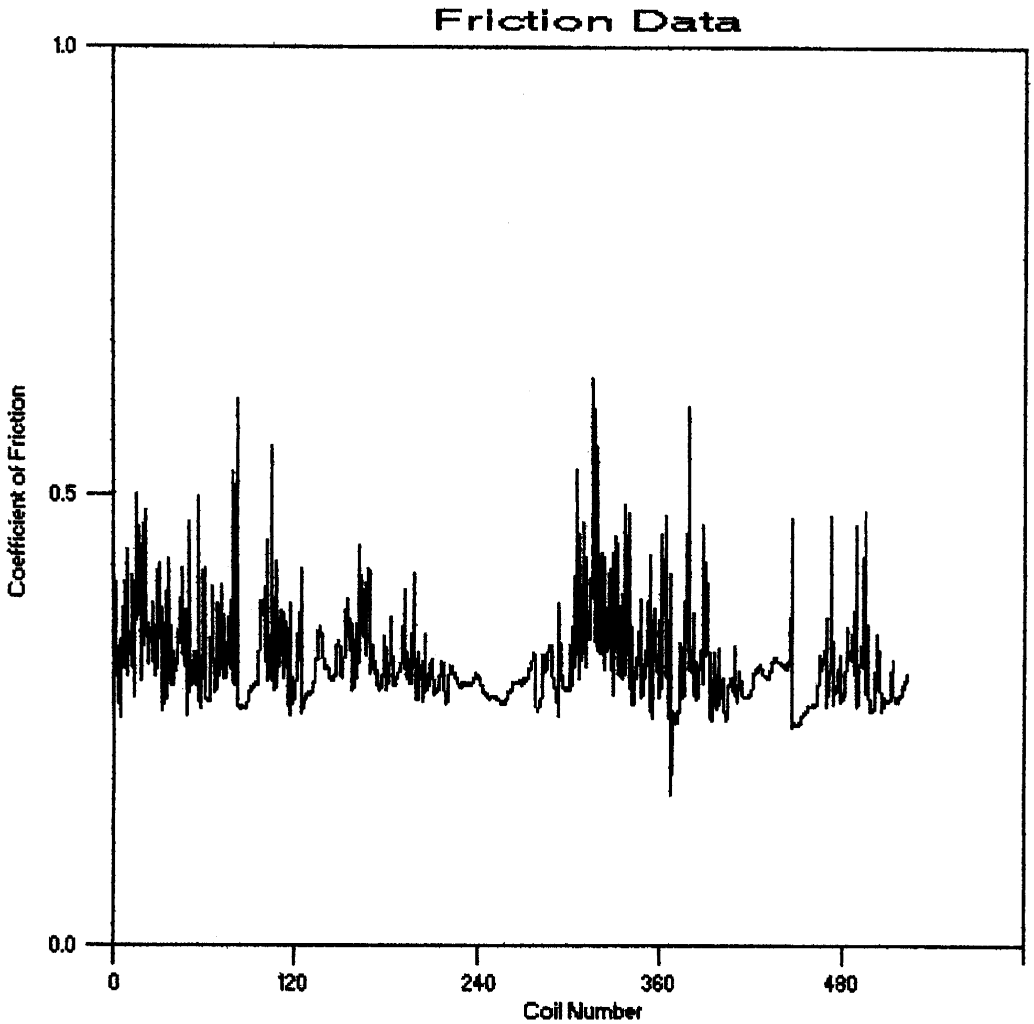

Figure 12 0.71mm 302 type stainless steel, wire 3

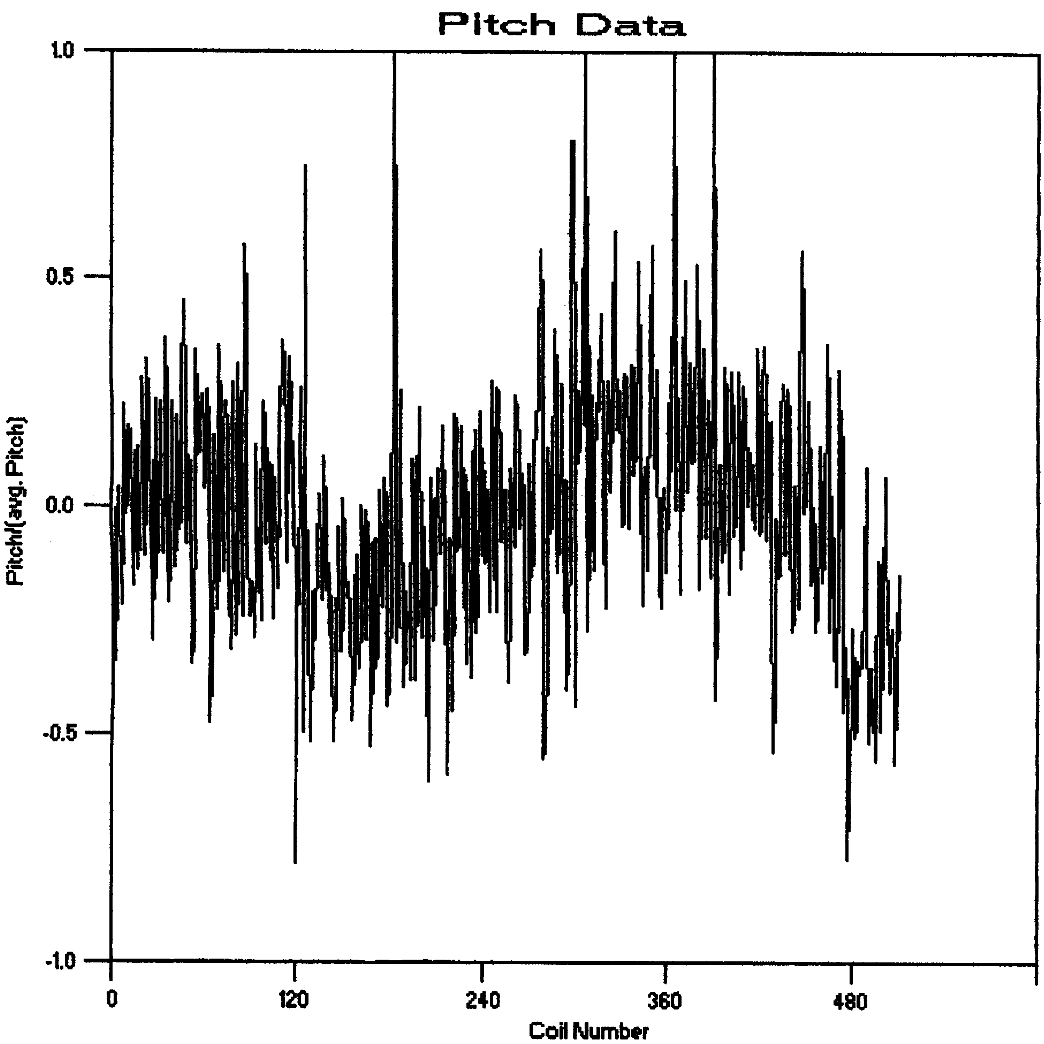

Figure 13 0.71mm pre-galvanised carbon steel, wire 4

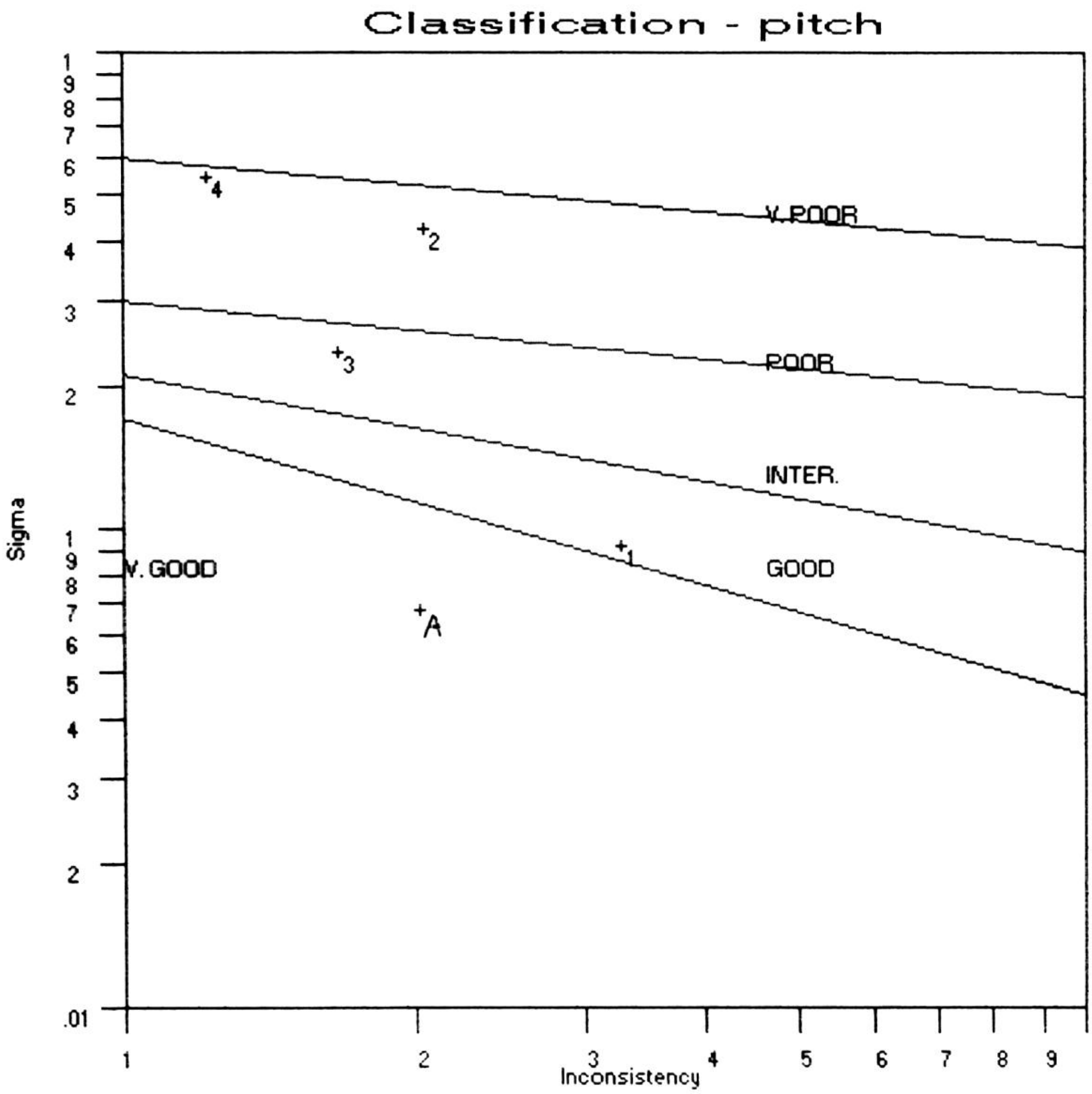

Figure 14 Coilability classification diagram for 0.71mm spring wires