PULSE INTERPOLATION - REVISION OF ISO 7278/3

by

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SUMMARY

ISO 7278/3 covers pulse interpolation for use in proving hydrocarbon flowmeters. The existing standard has been found to be inadequate in a number of respects, and requires revision. This paper describes the work done at NEL to provide data to allow an advisory table to be drawn up. The data has been produced by computer simulations of variable pulse intervals and a pulse interpolation system.

The results are compared with the present proposed revision of ISO 7278/3.

1 INTRODUCTION

ISO 7278 is the International Standard covering proving systems for volumetric meters used in the dynamic measurement of liquid hydrocarbons. Part 3, the section describing methods for pulse interpolation, was published in final form in 1987 and describes the methods and limitations of present pulse interpolation systems. These methods have been devised to increase the resolution of flowmeters, allowing them to be calibrated using relatively small volumes of liquids. A number of commercial pipe provers have been produced with small volumes, and it is the dependence of these devices on pulse interpolation that makes the need for a Standard extremely important. The original requirement arose from the desire to prove low resolution meters using conventional provers.

The Standard was produced using the data and experience available at the time, and has proved to be a useful document as far as describing the methods and their general limitations. A Table however was included in the Standard to advise on the minimum number of pulses required for different levels of variation in pulse time interval spacing. It is this variation in the time between incoming flowmeter pulses which is the limiting factor to achieving a repeatable calibration using pulse interpolation. Due to further work being carried out the number of pulses required to overcome the effect of this pulse variation has been underestimated in the Standard by a large amount.

A revision of ISO 7278/3 is at present proceeding with the main emphasis being on the development of a replacement for the existing advisory Table. It is extremely important that this revision is carried out as soon, and as thoroughly, as possible since other Codes and Standards are following the lead given by this Standard. To help provide more information on the relationship between the pulse variations, repeatability and the number of pulses collected, NEL has carried out computer simulations of prover systems along with the experimental work on small volume prover assessments. This has provided data which can, and will, be used in the revision of the Standard. This paper summarises this simulation work and describes the present proposed revision of the ISO document.

2 SUMMARY OF WORK ON COMPACT PROVERS AT NEL

A programme of tests was initiated at NEL some years ago to evaluate a number of compact provers in the laboratory. Three provers were tested and a summary was presented two years ago at the North Sea Flow Metering Workshop (Ref 1). All the provers showed that they operated well and could measure volume both accurately and repeatably. However they failed to calibrate some meters repeatably, but successfully calibrated others. The positive displacement meters fitted with gearboxes were the meters which did not calibrate well. Examination of the pulse intervals generated by several meters was carried out, and it was found that the spread of pulse interval variations was around 1 per cent for turbine meters and up to 30 per cent for positive displacement meters with gearbox drives (Ref 2, 3, 4).

Three other features were evident from the measurements of pulse time intervals. Firstly, it was seen that turbine meters, with eight blades, had a pattern of variation (Fig. 1) which repeated every revolution of the meter. This pattern, caused by irregularities in the blade spacing, did not follow any trend within a revolution. Secondly, the positive displacement meters also showed a repeating pattern (Fig. 2) due to revolutions of the meter. Because of the higher resolution of these meters, the pattern was a few hundreds of pulses long. This pattern, unlike the previous one, was characterized by a regular increase and decrease in pulse time across each revolution of the meter. The term given to describe these two phenomena is intra-rotational non-linearity (IRNL) and the two effects will be called irregular and regular IRNL respectively.

Thirdly, it was seen that there existed a completely random pulse variation superimposed on the patterns. When examined, this variation had an approximately normal distribution, although some examples showed broader or skewed distributions.

When testing the positive displacement meters with gearboxes using the three provers, it was observed that the calibration repeatability, although consistently poor, was different on each prover. No obvious explanation was found for this at the time of testing and the effect was thought to be either a faulty meter or electrical interference between the meter and the prover electronics.

3 COMPUTER SIMULATIONS OF PULSE VARIATIONS

To allow any guidance to be given in the Standard, it became clear that a relationship between the repeatability of calibrations, the pulse variation, and the number of pulses collected should be defined. It was even more obvious that the data for such a relationship could never be derived from flow testing since no control over either the number of pulses or the pulse intervals is possible.

To aid the revision of the ISO document, NEL produced a simulation program to investigate the various factors influencing pulse interpolation. The results of the simulations were presented (Ref 5) last year and have been used in the discussions of the Standard revision.

The program simulates the action of a meter prover with switches placed to enable the collection of any pre-determined number of evenly spaced pulses. The pulses are totalised to allow any one of the three pulse interpolation timing methods to be examined. Pulse intervals are modified within pre-set limits to simulate pulse variation. The first simulations were carried out with variations being chosen, between pre-selected limits, using a random number generator to give equal numbers of intervals spread between the limits (flat distribution). The program was later modified to give an approximate normal distribution between the limits.

For each pulse variation and chosen number of collected pulses, 20 passes of the prover were simulated, and the repeatability, R, calculated from the equation:

$$R = \sqrt{2}\,\sigma t \text{ per cent}$$

where σ is Standard deviation of interpolated pulses

and t is Students t at the 95 per cent confidence limit.

The mean of five repeatabilities was calculated to give the result.

The double chronometry method of pulse interpolation was used for all the simulations and the results are shown in Fig. 3.

From these results the following relationship was derived.

$$R = (0.08 + 0.52V)\frac{1}{\sqrt{P}}$$

where R is the repeatability (per cent)

V is the per cent spread of pulse intervals

and P is the number of pulses collected.

The number of pulses necessary to meet the oil industry requirement of ±0.02 per cent repeatability could now be calculated for any level of pulse variation. This was done and the result is shown in Table 1 along with the values recommended in ISO 7278/3.

4 REVISION OF ISO 7278/3

From experience of compact provers in the field, the predicted number of pulses required to give acceptable repeatability was considered to be too high. This conclusion was based on the data presented from flow tests using small volume provers, but without much evidence of pulse interval variation levels. Where pulse intervals had been measured, only the range of intervals was given and no information on the distribution of intervals or the intra-rotational non-linearity. A revised Table showing the minimum recommended number of pulses has been drawn up as a first draft estimate for discussion. These show values which are a best compromise between the results of flow experience in the field and the simulations.

This information, Table 2, is designed to give guidance on the minimum number of pulses collected to avoid significant error. The level of repeatability expected from this condition is not stated nor is the definition of 'significant error'.

A further modification to the Table has been made to change the expression of the pulse variation from a spread to a standard deviation of pulse intervals. This change enables a more statistical approach to the measurement of pulse intervals to be made and allow, to some extent, for the distribution of the intervals. However, it does not account for intra-rotational non-linearity except in the most general way. This modification has allowed a statistical analysis of the relationship between pulses and repeatability to be carried out by Hayward (Ref 6), the results of which have been incorporated in Table 2

To compare these results with the NEL simulations, an assumption has to be made to convert range to standard deviation of pulse intervals. The range is assumed, for the large pulse numbers concerned, to be six times the standard deviation, which is an approximation which is thought to be acceptable. Again the results are given in Table 2.

For standard deviations up to 5 per cent, reasonable agreement is found between the predictions taken from simulation and statistical analysis. Above 5 per cent agreement is not as good, but since this corresponds to a variation in spread of 60 per cent, it is beyond the scope of the simulation.
One of the arguments for choosing a lower number of recommended pulses than are shown in either of the two theoretical approaches is that IRNL will allow the full range of the pulse variations to be ignored and only the random component of the variation need be counted. To examine this argument further, simulations were carried out with both regular and irregular IRNL.

5 SIMULATION OF IRREGULAR INTRA-ROTATIONAL NON-LINEARITY

Irregular intra-rotational non-linearity as would be produced by a seven bladed turbine meter was simulated. This was done by defining a pulse pattern and changing its spread to fall within set limits. This pattern was repeated every seven pulses, and the effect was superimposed on a random variation as described in Section 3.

The results of a simulation are shown in Fig. 4, where a 2 per cent random variation had a 10 per cent irregular IRNL superimposed on to it.

The repeatability is close to that expected from a 2 per cent random variation alone.

6 SIMULATION OF REGULAR INTRA-ROTATIONAL NON-LINEARITY

Regular IRNL, as might be produced by a high resolution positive displacement meter, was also simulated. In this case, the variation in pulse intervals was calculated using a sine function based on a selected cycle length. Again this effect was superimposed on a random variation.

The first simulation, Fig. 5 had a cycle length of 200 pulses with a pulse variation spread of 10 per cent. This was superimposed onto a 2 per cent random variation. It is observed that if the number of pulses collected is an exact multiple of the 200 pulse cycle, a very low repeatability is found. Between these numbers, however, the repeatabilities vary markedly.

A second simulation was carried out over a small range of pulses using a 100 pulse cycle. The cycle variation of 10 per cent was maintained along with the 2 per cent random variation.

The results are shown in Fig. 6. Across the range of pulses collected, the repeatability rises and falls regularly, with the lowest repeatability being found at exact multiples of one hundred pulses and the highest being mid-way between these points. The shape of graphed results is best described as a decaying fully rectified sine function. These findings indicate why the NEL calibrations of a positive displacement meter showed different repeatabilities when calibrated using different volumes of prover.

The repeatability will depend not only on how many pulses are collected, but on how many meter revolutions occur during a proving pass. More importantly, the magnitude of the fraction of a meter revolution, over and above whole revolutions, has a great effect on the repeatability of the calibration.

To investigate the effect further, a further simulation was carried out over a much larger range of collected pulses. In this case a cycle length of 200 pulses was chosen with the same levels of variation applied, ie 10 per cent cyclic, 2 per cent random. For each pass, the number of pulses collected was either a multiple of 200 pulses or the intermediate points. Fig. 7 shows the results. Two random variation curves have been drawn. The first curve is for a 2 per cent random variation alone from which it can be seen that when the pulses collected are a multiple of the cycle length, the cycle variation can be ignored. Between the multiples of the cycle length, the repeatability is poorer than would be expected from random pulse intervals of 10 per cent.

It appears that it would take many hundreds of meter revolutions to reduce the highest repeatabilities to the same level as a 10 per cent random variation, far less that expected of the underlying 2 per cent random component.

Two observations should be made at this time. Firstly, in simulating this regular intra-rotational non-linearity, each pass was started at a randomly chosen point in the cycle. Secondly, the standard deviation of the pulse intervals for a 2 per cent random and a 10 per cent regular variation was 3.5 per cent.

7 CONCLUSION

ISO 7278/3 is undergoing revision, and apart from a few minor changes, the most substantial modification lies in the guidance table. The original table, which recommends the minimum number of pulses required to be collected, is now clearly inadequate. The revised table being proposed increases these minimum recommendations substantially.

The work described in this paper indicates that, for pulse interval variations which are random, the revised figures are still perhaps a factor of ten too low to meet repeatabilities of ± 0.02 per cent. If irregular intra-rotational non-linearity is a large component of the variation measured, the estimates are perhaps reasonable, as the variation due to the meter rotations can be discounted. The position when regular intra-rotational non-linearity is present is much more complex. The repeatability varies greatly with the fractional part of the number of meter cycles in a proving pass. This explains why a lack of consistency has been found in the ability of compact provers to calibrate various types of meters, particularly positive displacement meters. If the prover volume and the meter revolution match or nearly match, good repeatability is found; if they do not extremely poor repeatabilities is obtained.

How this effect can be resolved within ISO will require much discussion. It is made especially difficult since the data on pulse variations, meter revolutions, and prover volumes from field tests are not available to verify the simulations.

REFERENCES

1 PATON, R. Experience with compact provers and pulse interpolation at NEL. Paper 5.1, North Sea Flow Metering Workshop 1986, October 1986. National Engineering Laboratory, East Kilbride.

2 PATON, R. An evaluation of Brooks compact prover. Flow Measurement Memo 376, April 1988, National Engineering Laboratory, East Kilbride.

3 PATON, R. An evaluation of Smiths systems small volume prover. Flow Measurement Memo 370, August 1987, National Engineering Laboratory, East Kilbride.

4 PATON, R. An evaluation of Daniel Industries small volume prover. Flow Measurement Memo 378, May 1988, National Engineering Laboratory, East Kilbride.

5 PATON, R. Predictions of flowmeter calibration repeatability using compact provers and pulse interpolation. Industrial Flow Measurement Onshore and Offshore, September 1987, IBC Technical Services.

6 HAYWARD, A. T. J. A simplified statistical analysis of the effect of pulse spacing variations on the repeatability of meter proving where pulse interpolation is employed. SGS Moore, Barrett and Redwood Ltd, RTN203, June 1988.

TABLE 1

COMPARISON OF PRESENT ISO RECOMMENDATION AND PREDICTION

Pulse interval variation %	Present ISO recommended minimum	Prediction for random variation R = 0.04%
1	50	225
2	100	280
5	250	4400
10	500	17000
20	1000	67000
30	1500	150000

TABLE 2

COMPARISON OF PROPOSED ISO RECOMMENDATION, PREDICTIONS AND STATISTICAL ANALYSIS

Irregularity of pulse spacing standard deviation %	Minimum number of pulses to be collected during a proving run		
	ISO	Statistical spread within 0.04%	Predictions *1 R = 0.04%
0.5	100	1300	1681
1.0	400	5000	6400
2.5	2500	30000	38800
5.0	10000	125000	153000
10.0	40000	280000	611000 *2
15.0	90000	500000	1373000 *2

*1 This assumes Standard deviation = 1/6 range.

*2 These points are beyond range of variations covered.

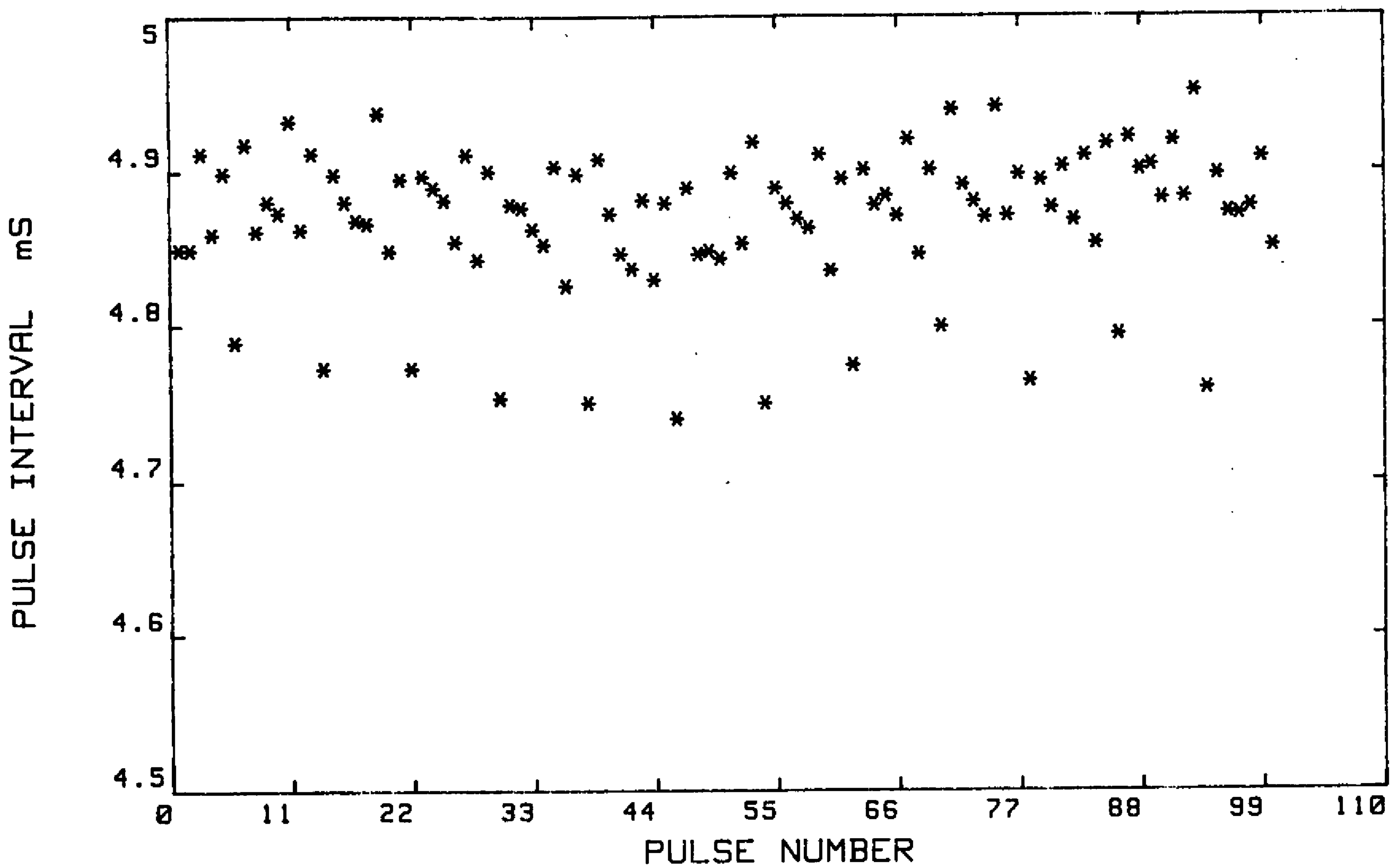

FIG I PULSE INTERVALS FROM TURBINE METER

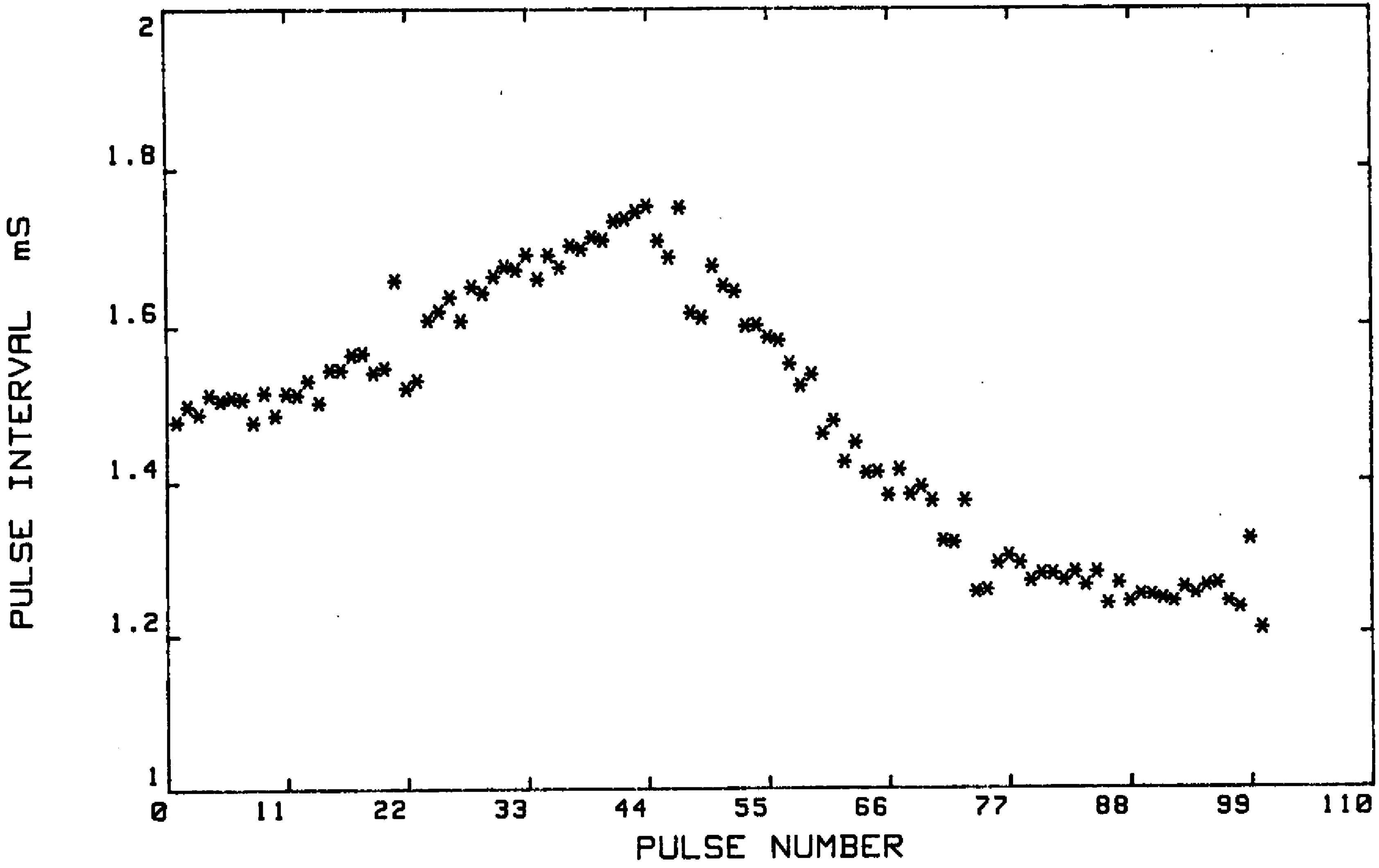

FIG 2 PULSE INTERVALS FROM METER

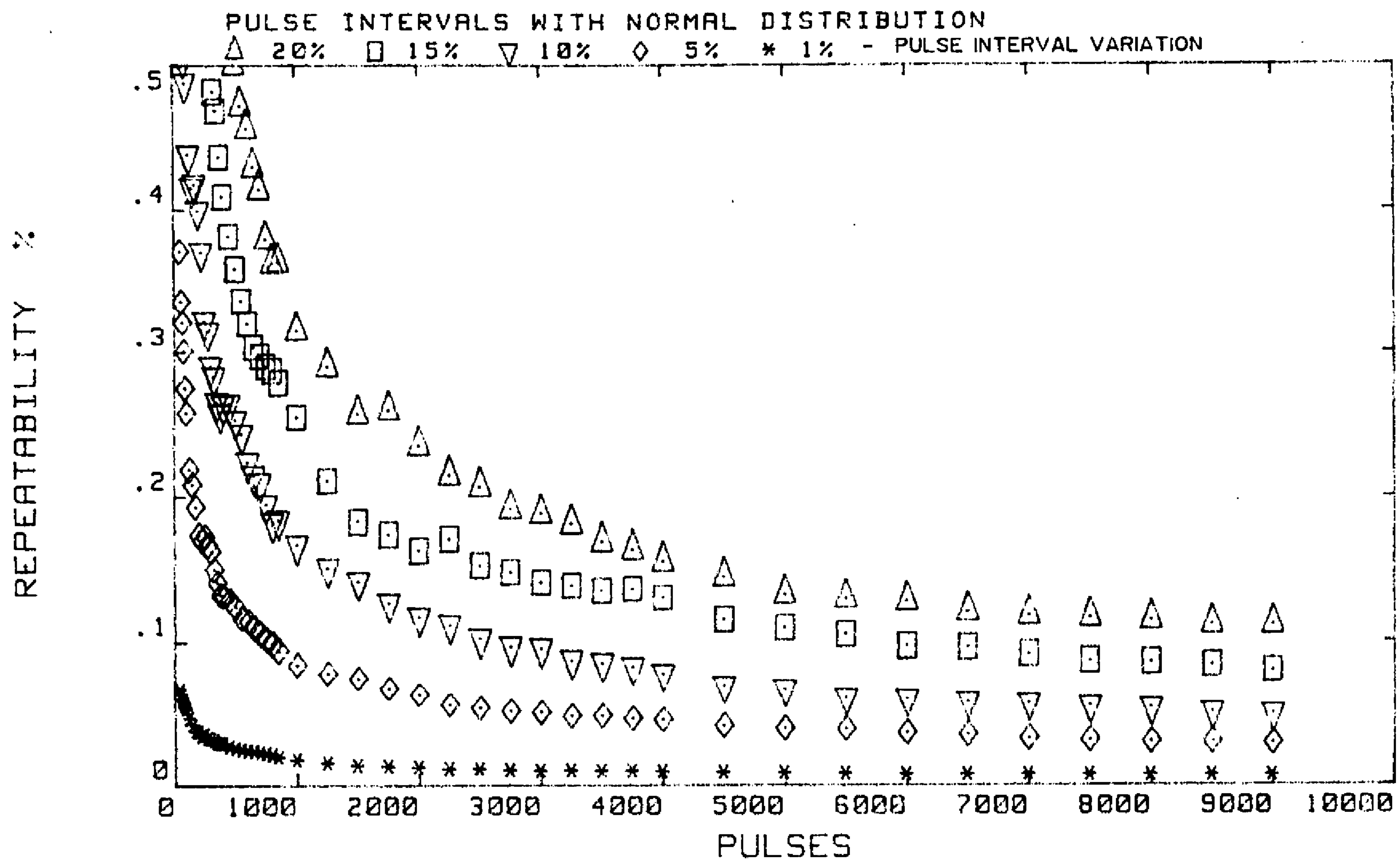

FIG 3 REPEATABILITY FOR DIFFERENT VARIATIONS

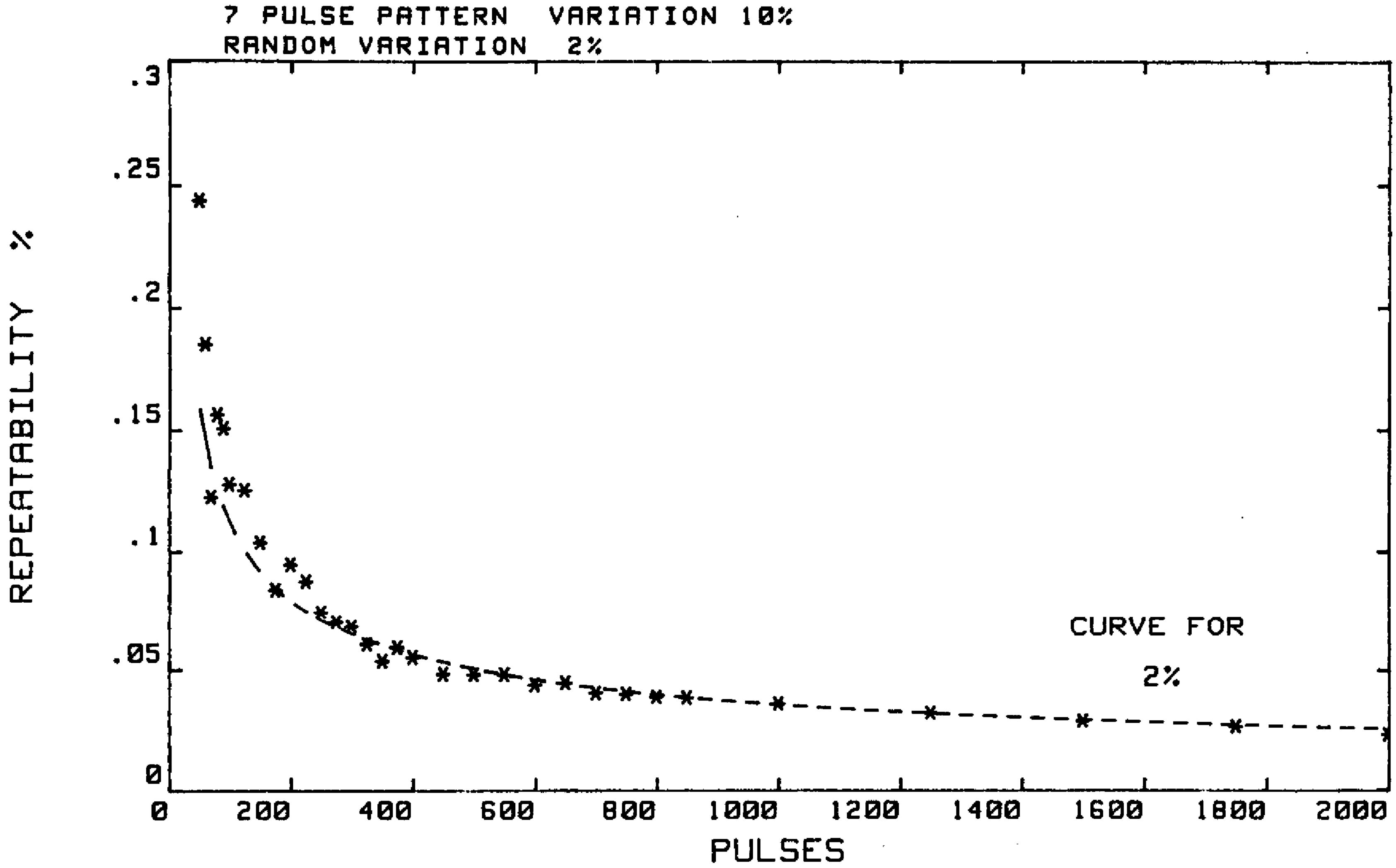

FIG 4 IRREGULAR INTRA ROTATIONAL NON LINEARITY

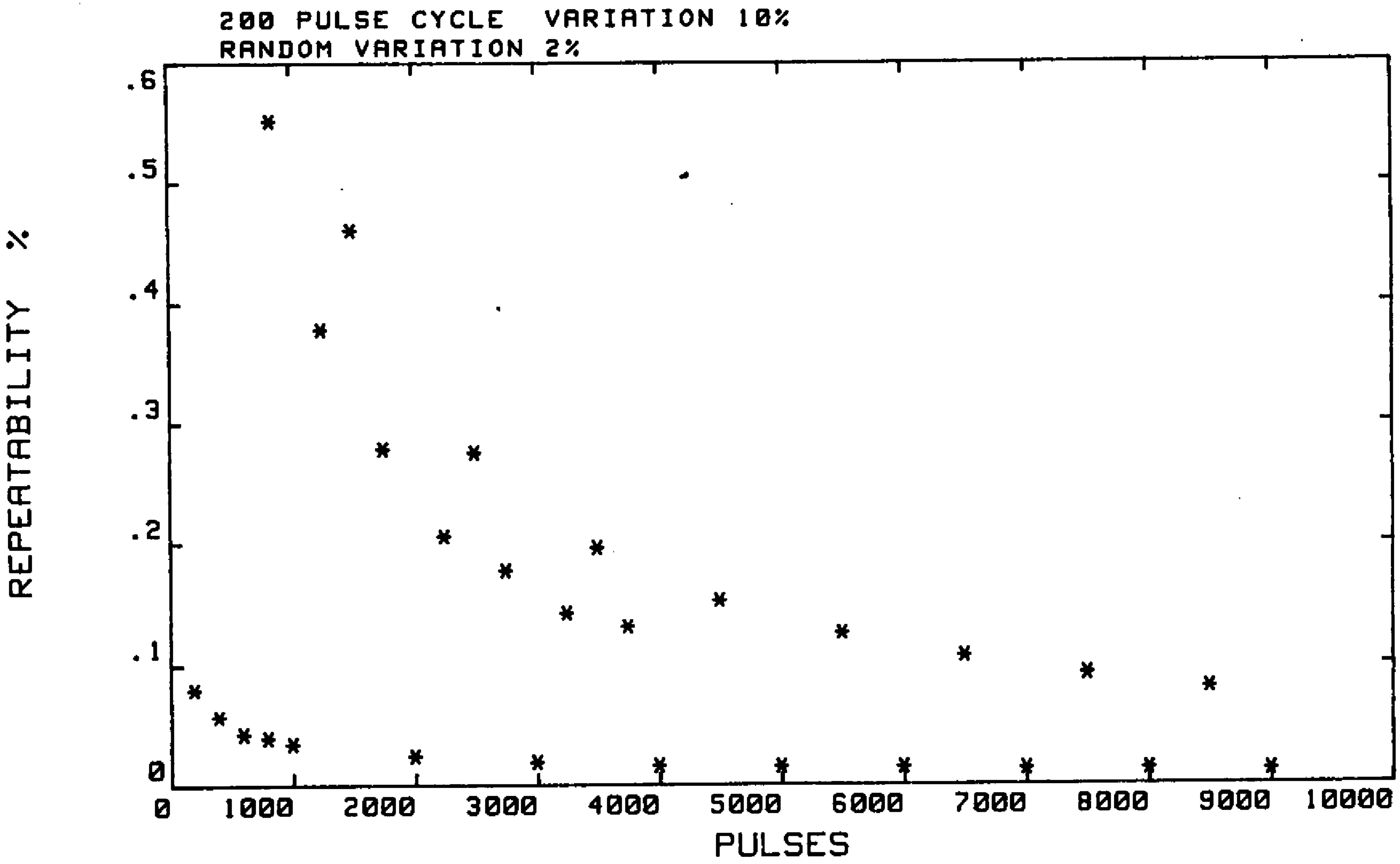

FIG 5 REGULAR INTRA ROTATIONAL NON LINEARITY

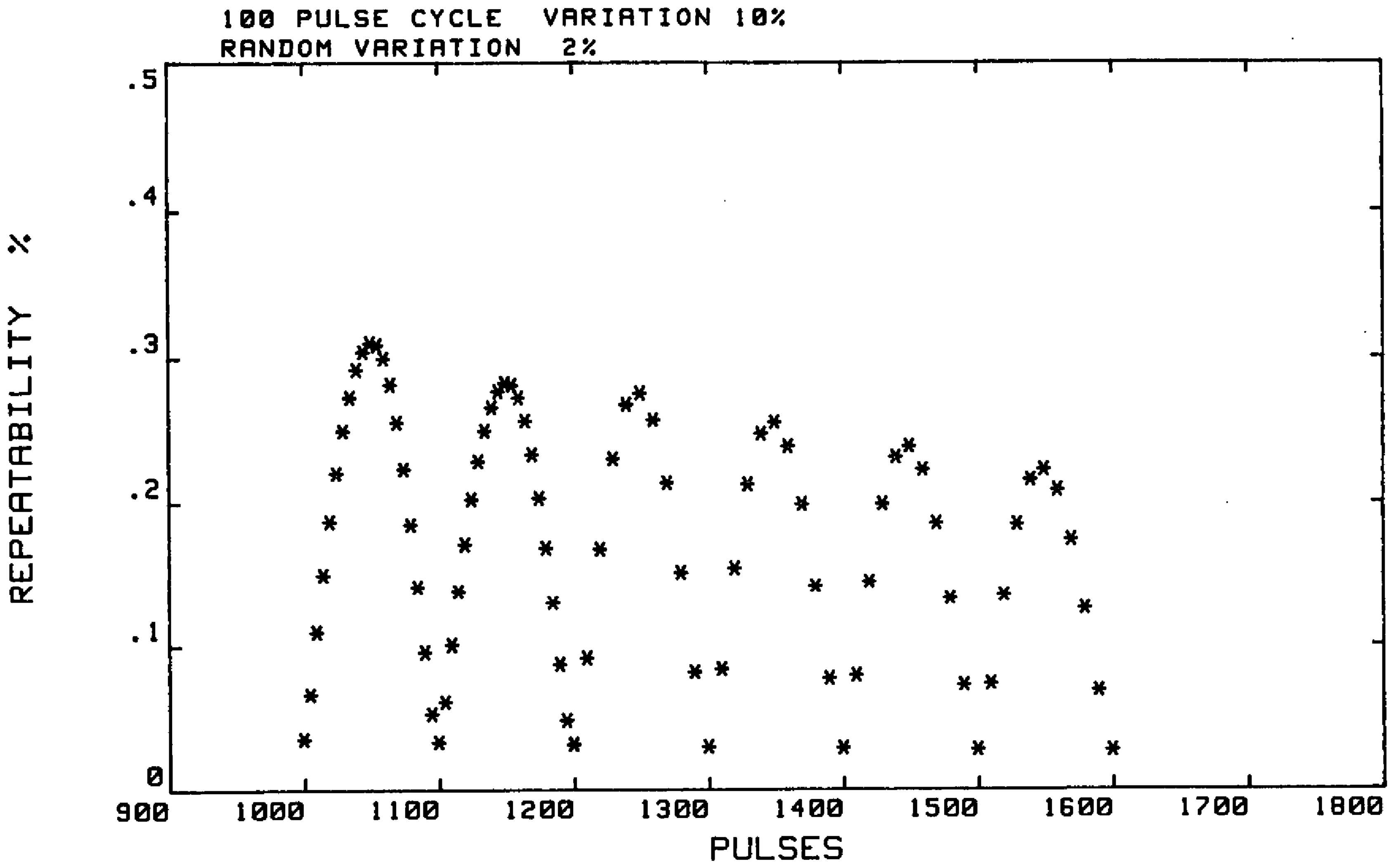

FIG 6 REGULAR INTRA ROTATIONAL NON LINEARITY

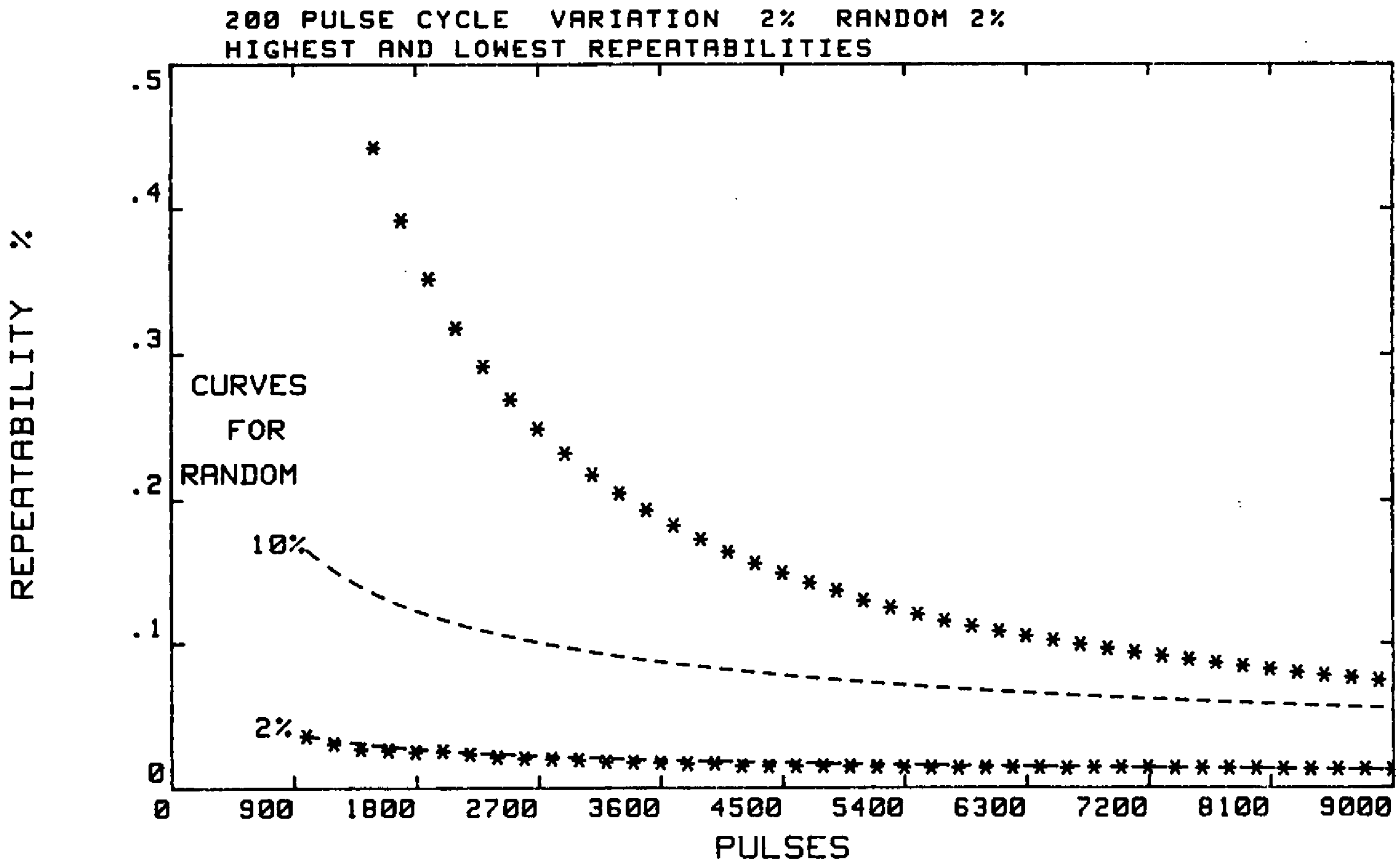

FIG 7 REGULAR INTRA ROTATIONAL NON LINEARITY