In conclusion, the equipment in its developed form appears to be superior to any other system in use at the present time for accurately assessing oscillatory and steady stresses in rotary wing aircraft

The equipment's relatively small bulk and weight have enabled full scale testing to be carried out successfully in the world's smallest fully articulated helicopter, yet these former considerations have not in any way reduced the scope of measurements or reliability

Due to careful design and development in parallel with flight testing facilities, the requirements of the user have been satisfied, resulting in a flexible and functional set of flight test equipment The individual appraisal in flight of stress levels on the display unit is complementary to relevant attenuating facilities, the advantages of this are considered to be of great importance

The method of amplifying relatively small signals with thermionic valves and passing the amplified signals in a voltage form has proved itself not only practical, but superior to direct recording systems in use in the United Kingdom or the Continent

Maintenance requirements for the equipment are average, bearing in mind its relatively complex nature

The separate unit system makes maintenance much easier The fact that strain gauging blade motion calibrations are made directly dispenses with the hazards of calculation errors and makes analysis of oscillatory and steady stress quantities simpler and quicker

In general, these characteristics are due to the original conception and sound electronic design, married to the experience gained in the field which have led to a major step forward in helicopter stress measuring techniques

I would like to thank the Ministry of Supply for permission to quote certain details relevant to this equipment, I am also indebted to Saunders-Roe Ltd for facilities and permission to present this Paper

I would point out that the opinions quoted herein are not necessarily those of Saunders-Roe Ltd

Discussion

The **Chairman** said it had been a most interesting lecture on a subject which those who were involved in both design and manufacture found it necessary to tolerate ! The Author's review of the methods and systems had been most stimulating future the instrument they wanted to use would be a magnetic tape recorder At

The Chairman added that as he was not himself an electronic expert, he would like those most competent to do so to comment and criticise and give their contributions to the discussion

Mr R Trumper (*Test Superintendent*, *Fairey Aviation Co* , *Ltd*), said he had listened with great interest to an excellent summary of instrumentation, because he had been faced with similar problems in the last few years at Fairey's They had had to think of suitable instruments for use on their large helicopter, the Rotodyne, and their ultra-light machine

To his pleasure and surprise, he found that Saunders-Roe and Fairey's had very much the same views on the correct procedure in instrumentation *i e* , that in the future the instrument they wanted to use would be a magnetic tape recorder At the present time the mirror galvanometers, which had been used in propellor testing for many years, were probably the best for large helicopters For small ones the Hussenot recorder, together with some form of amplifier, appeared to be the best

https://doi.org/10.1017/S2753447200003206 Published online by Cambridge University Press

As Saunders-Roe had dealt with their small equipment in some detail, Mr TRUMPER felt it would be wise if he did the same. Fairey's equipment was really a great deal more simple, for two reasons. First, they used slip rings without any pre-amplifier, and, surprisingly, they did not seem to have any real trouble in so doing. The other feature which made it simple was that they had done away with monitoring, because in their opinion one had a pretty good idea of the stress levels to be recorded and the attenuator could be pre-set suitably before flight. In a little helicopter, if a flight had to be repeated it was a matter of no great expense or moment. Therefore, they were prepared to sacrifice an occasional wasted flight because in turn they gained a great deal of simplicity and reliability.

Mr TRUMPER'S first slide showed how simple this equipment was. They used a Hussenot recorder fed directly from the amplifier, some 6-in. in length and of about the same width, which was supplied from dry batteries. The strain gauge signals were taken directly to the amplifier and into the Hussenot recorder. The performance of this equipment was flat from about 2 cycles per second to 100 cycles per second. Three-channel recording was used and a switch in the cockpit enabled the pilot to switch in another three gauges if necessary. The total weight was 57 lb. as a three-channel recorder with amplifiers and batteries.

His second slide showed the type of slip ring, which was developed directly from the propellor testing they had done. When it was borne in mind that propellor strain gauging had been mandatory for 15 years and in that time several hundred propellors must be cleared, in flight as well as on the ground, it was not altogether surprising that a reasonably reliable strain gauge slip ring could be designed. In Fairey's opinion and experience—which had been quite large—the slip ring shown in the illustration would give at least five hours' running without any pre-amplification, and on opening it up, which could be done merely by undoing the nuts and bolts and cleaning it, 20 hours' life could be obtained from it without any real trouble. The leaf springs were an important feature. Coil springs, when used to load the brushes, always gave trouble.

The third slide showed a slip ring assembly used behind an aircraft propellor. This was usually a much more difficult problem because of the very high rubbing velocities of the outer rings. An aircraft propellor probably ran at 1,400 r.p.m. as against the 400 r.p.m. in the case of the small helicopter. The type of equipment illustrated would give satisfactory recording for several hours, provided one made sure that there were no oil leaks from the oil seals on the propellor shaft. It had been used successfully in the flight testing of several propellors.

In these circumstances, he felt that they should have no hesitation in using slip rings of this nature provided the one precaution was taken of using a high resistance strain gauge. Some propellor companies used them up to about 10,000 ohms instead of Fairey's figure of 2,000 ohms. If a slip ring was used in series with strain gauge, the noise from the brush was inversely proportional to the gauge resistance. He wondered whether some of Saunders-Roe's troubles had been due to the use of a low resistance gauge.

Referring to magnetic tape recording, he said it was usually assumed that all the information acquired from a strain gauge record could be obtained by a harmonic analysis. This was not really true, because if, for example, one considered a square wave acting on a piece of metal, the metal only knew it had been taken from a low level of stress to a high one, whereas if a harmonic analysis of this wave form was done automatically or by any other means, it would be found that there was a series of harmonics. He was sure it would be the wrong technique in fatigue testing to apply those harmonics rather than a single change of stress from one level to another. For this reason, in the equipment for analysing automatically information taken from magnetic tape recorders, what was wanted was a device that would count the number of times that the stress passed from one level to another and back again as well as a harmonic analysis.

He wished to cross swords with the Author on the question of the measurement of steady stresses. The values which had been quoted as levels on which reliable measurements could be taken were about 3,000 lb./sq. in. He agreed that this was possible in a laboratory, but in actual fact a strain gauge was such a sensitive indicator of temperature differences that in practice he did not think this was really possible.

His fourth slide showed the variation of resistance of gauges against temperature. It would be noticed that the equivalent stress on steel for a given temperature change was about ¾-ton per square inch for a 1 deg. C. rise in temperature. Therefore, to get any reasonable accuracy if measuring 3,000 lb./sq. in., the temperature difference of the gauges must be within about one-tenth of a degree For this reason, Fairey's tried not to measure low steady stresses, but to put a device into the circuit to enable them to measure the loads or torque with a high stress level suitably designed to protect it against any overloading They had done experiments, on the temperature sensitivity of normally compensated gauges and he would be interested to know how Saunders-Roe gauges would compare with those to be shown on the next slide

Mr TRUMPER added that the gauge to which he referred particularly was a self-compensated gauge that Fairey's made using the same principles as those of Baldwin and Southwick It showed a remarkably small change of resistance with temperature and if used with a compensator in the ordinary manner, it was possible to get a very high order of accuracy indeed

His fifth slide showed what slip ring trouble was like These results, which were almost of historic interest, were taken with carbon gauges on propellors They were quite nice, smooth, regular wave forms on the absence of slip ring trouble which when it did occur was unmistakable, but should not arise if one was careful One of the readings was a typical one taken with Fairey's apparatus on their ultra-light helicopter and showed that switching on the apparatus made a definite change of resistance to the bridge circuit, which showed a step on the record which was in effect, directly proportional to a stress and was used as automatic calibration

The final diagram showed a wiring trouble which sometimes occurred when, by bad work, a loose wire was left and the vibration produced a false signal

The **Author,** in reply, said that all this gave him quite a lot to think about It was not a case of one man's meat being another man's poison It was interesting to see how very akin in some respects was the two companies' approach to the same problem Mr TRUMPER had, however, pointed out some differences, there were also others

In the case of measurement of stresses in propellors, the stress levels were usually somewhat higher than the stress levels that were often measured in components like flapping links in drag bending in helicopters The whole problem of signal to noise ratio was proportional to the size of the signal to be played with

Saunders-Roe had a system which would go down to a signal level of the order of 1 millivolt and would reproduce it quite faithfully The AUTHOR said that the ultra-light, not having a piston engine to contend with, he would imagine that the vibration levels were not quite so high There might be vibration levels of another type When one considered battery operated valves in an aircraft with piston engines, they simply would not stand the relatively high vibration levels they would very soon become unserviceable He would not countenance their use on any account in an orthodox helicopter

He could not show a slide with figures of drift for Saunders-Roe gauges, but he qualified his statement by saying " Saunders-Roe foil gauges when suitably treated " They had developed a very satisfactory system of coating strain gauges in such a way as to protect the gauge physically from damage , it was an interesting facet of strain gauging technique At one time, it was just sufficiently good enough to clean the surface, fix a strain gauge on it, hope that it was satisfactory, connect it up and use it , but if the component was in some integral part of the aircraft, entailing many man hours' labour to remove it, and if in assembly the strain gauges were accidentally damaged a great deal of money and delay could be involved in getting on with the job

They had, therefore, devised a method of coating the gauges to protect them and had resolved a certain mixture of araldite 101 This coating also ensured maximum compensation where temperature differentials are encountered Furthermore, on the question of impedance of strain gauges, the AUTHOR said he did not think Mr TRUMPER quite realised that they were not actually working directly from the gauge Granted the gauges are primarily of low resistance, but from the output of the pre-amps into the monitor unit, it was a high impedance, in the order of 10 to 20 meg ohms This was considerably better than anything the high resistance gauge could do, with particular reference to noise levels through slip rings

Reviewing one or two traces briefly, he dealt first with the results obtained from the rotor Test Tower Fig 6 showed something which looked almost too good to be true Very early in the testing of this equipment, due to the fact that the strain gauges on some parts of the hub were not sufficiently flexible, they had to change over to little springs which were actually operated by the cyclic motion of the flapping links They were left with the torque signals being the only calibrated data The remaining signals were blade motion, in the flapping sense, from potentiometers transducers connected as he had described earlier, there was an azimuth signal for one complete revolution This is arranged for direct relation to the loads in the hub geography

The illustration shows more signals from the rotor Test Tower In this equipment it was possible to check the response from each channel before and after the test, except when potentiometers were being used, in which case the pre-amplifier was removed from the turret and connected directly into the system In the example in question, the response from the channel would not appear, but it was important to be able to measure the response of amplifiers before and after a test

The AUTHOR added that he was quite satisfied with the quality of the traces from this test work

Mr Trumper said that his question had not really been answered He agreed that there would be a high impedance with the slip rings, but asked why the amplifier should not be put in the aircraft, free from vibration and draughts, using a high resistance strain gauge directly to the slip rings

The **Author,** in reply, said one very good reason was that Saunders-Roe made their strain gauges, and it was only natural that they should use them ! There was, however, another very good reason which he would put forward with all respect to everybody else who made strain gauges A representative of a very old firm who had been making instruments and strain gauges for many years, had said during a visit, that his company used Saunders-Roe gauges and in their opinion they were one of the most reliable strain gauge elements in the world The AUTHOR expressed the view that the only gauge to come anywhere near to it in comparison was the Baldwin gauge

The foil gauge is rugged, reliable and consistent in performance He did not see any good reason for saying that with a high impedance gauge, with the kind of loads they had been measuring, they would not get the signal to noise ratio problem One was bound to run into trouble when trying to measure very small levels It was satisfactory for large loads, but not for small ones

It seems that Mr TRUMPER is determined to place great faith in a technique which puts the cart before the horse I cannot see any logic, once a case for amplification has been admitted, and that an A C device, for amplifying slip ring transmission noise which, as we have seen from the quality of the recordings, does occur

The desirability of rotor head mounted amplifiers had been argued for years, but nobody had successfully undertaken their design and development Now that this has been achieved, regardless of the proven benefits harvested by Saunders-Roe, we must concede that any other equipment is better, simply because it is in opposition to a functional measuring philosophy This is neither intelligent nor progressive

Mr Trumper observed that the magnitude of the stress in question was about 1—2 tons/sq in in steel

The **Chairman** suggested that as a number of members were anxious to contribute to the discussion, Mr Trumper might pursue the topic after the meeting

Mr A F Appleton (*Head of the Electronic and Vibration Laboratory, Bristol Aircraft Ltd , Filton*), said that his comments were similar to those expressed by Mr Trumper, especially in relation to the passing of strain gauge signals through slip rings The Bristol Company had been dealing with problems of this kind for some time and they have found it quite unnecessary to even consider the use of pre-amplifiers with slip rings Fortunately, in many cases the measured strains and hence the signals were quite high largely because they are using wooden rotor blades

For the past five years or so, they had got away quite nicely using 1,000 ohm strain gauges, and more recently in some cases 400 ohm, strain gauges, provided of course that a complete four arm bridge circuit was always used The use of two arm or half bridges almost invariably spelt trouble

Judging from the slides shown by Mr Trumper, the slip rings used by the Bristol Company on the rotor hub were similar in design to Fairey's Similarly, they were developed from a propellor type of slip ring

Recalling the Author's remarks that he had experienced many difficulties when using A C , Mr APPLETON said that his company had used the Miller 6 channel, 2 kc carrier amplifiers and similar equipment for many years with satisfactory results

Referring to tape recording, he said that the Mervyn instrument seemed to have interesting possibilities and perhaps the greatest advantage of this type of instrument was the speed at which analysis of the data could be performed He did not entirely agree with Mr Trumper that all that was wanted was to count the number of times the stress changed from one level to another It was, of course, very desirable to do this, but it was also necessary to do harmonic analysis to provide information for use in subsequent design stages where knowledge of the frequency and source of oscillations as well as their amplitude and phase relationship is particularly useful This is especially true when power operated controls and other similar devices form a part of the system

The **Author,** in reply, said he had overlooked Mr TRUMPER's question concerning analysis of harmonically related wave forms and the lack of need for it As he said earlier, he had always been fortunate enough to be able to get hold of phenomenon which was pronounced once per rev load with no unharmonically related thing about

Mr APPLETON probably had in mind, as he had himself, the possible resonance in a bonded metal rotor blade which might give unharmonically related data If this occurred with the Saunders-Roe blade, it would be essential to know exactly what the harmonic relation was Under those circumstances, it would be essential In fact, at a demonstration of the Pametrada analyser with Mr Woods of Muirhead's, they had excited a piece of metal for him They knew exactly what was going into it, and he found no less than eight unharmonic related wave forms This showed how easily it could happen

On A C energisation, in the case of measuring stresses in blades, expecially in a bonded blade, where the conductors must be run at great length along the outside of the blade—as both Mr Appleton and himself had done, the AUTHOR said that in his opinion trouble was likely to be encountered, especially when trying to interpret small steady loads

Mr Appleton replied that he had not experienced it

Mr F N R Ballam (*Electronics Engineer, Westland Aircraft, Ltd*), said he was more or less in agreement with Mr TRUMPER and Mr APPLETON on most of their points Westlands had been doing this business fairly quietly for some five or six years with a fair degree of success They began with no previous knowledge of how to do the job They had never had to measure stresses on propellors or anything They started with somewhat crude slip rings of their own design, but eventually got them to work, at the same time using high resistance strain gauges in full bridges On most occasions they had not run into trouble with temperature compensation

They had managed to measure their steady stresses right from the start with a fair degree of accuracy and without much trouble from drift, using carrier amplifier equipment Their recorded wave Forms had on the whole been as clean as those shown by the author They had frequently produced much worse wave Forms but under average conditions most of them were better than or at least as good as those illustrated by the author

He was not sure why the author had gone about it the hard way as putting pre-amplifiers up on the rotor head seemed to have made the whole thing unnecessarily difficult If one was prepared to accept " drastic curtailment of frequency spectrum " most of the necessary frequencies up to 30 cycles per second could be covered by direct recording with galvanometers

Westlands had on one occasion at least, successfully done their blade stresses by mounting the recorder on the rotor head, using Teddingtons SE/A/12 strain gauges which had been run for short periods on quite high voltages They had not experienced much in the way of D C drift and had got quite satisfactory recordings

He did not quite understand why people were so worried about accuracy on low level stresses If the stresses were so low what did the accuracy matter anyway—unless one wanted to measure loads for someone's aerodynamic assessment of the rotor system and so on He was not certain why people placed so much stress on this accurate measurement of the low stress levels

Incidentally, Westlands had been directly calibrating all of their equipment right from the start They injected a calibration signal on to the trace during each record, and before and after flights they did mechanical calibrations of all the components quite satisfactorily They normally expected to get agreement better than 5 or 6 per cent on all these calibrations, both mechanical and electrical For most purposes Mr BALLAM thought that this was as accurate as anyone could hope to achieve It was on both steady and vibratory stress levels

The **Author,** in reply, commented that the big guns were being fired at him on the question of having pre-amplifiers mounted on the top of the hub It was true that some people went the long way round to any problem, but there were sound reasons for mounting the pre-amplifiers on top of the hub This was linked with the other question of why people worried about minimum stress levels He could not conceive how it was possible to know, that vibratory stresses were small, unless they could be measured as such

If, for example, one was measuring from a quiescent position, from something, to something else which was in itself a relatively small quantity, it could either be smaller than bigger, or bigger than smaller He was not trying to be confusing, but meant to show that one must be able accurately, to measure the small quantities to know whether or not they were small

Mr Ballam, who said he had perhaps been misleading, explained that by 'accuracy' he meant percentage accuracy If something like ± 5 per cent or even ± 10 per cent on the low levels was maintained then surely this was quite adequate

The **Author** replied that it was quite adequate, if maintained, but there was the question of adding that to a number of other errors If consistency could be established, it was possible to establish accuracy, because eventually it was found by experience what the errors were , but one could not even guarantee from the morning to the afternoon that the conditions in which the machine was flying were identical

Mr Ballam said that in that case a lot of flights were necessary

The **Author,** in replying, said that was what users of inaccurate equipment were forced to do There was, however, a case for saying that a set of circumstances can arise in which one test flight could be done, and then another , and if the system was basically accurate for measuring small quantities, there would be no need for the third or fourth flights, which would be required with other equipment which had poor consistency characteristics

Mr Ballam said that he disputed that

The **Author** then introduced Mr DOBSON, who had kindly offered to explain in more detail the principle of analysis with his equipment

Mr K G Dobson (*Mervyn Instruments, Ltd*), explained that the function of the Analyser was merely to perform a full and complete automatic analysis of all the information there was in a wave form A Fourier analysis was just exactly that that was what it did He was not in agreement with Mr TRUMPER in saying that he did not want a harmonic analysis or Fourier analysis There was nothing else in the wave form anyway

The method of carrying out the analysis was that one sees one s record being reproduced in analogue form on the pens A portion of interest is then selected by pressing a knob and is re-recorded in a loop, and the answer is presented drawn up in graphic form on paper The analysis is a complete one with a very high degree of accuracy, far higher than could be arrived at by any mechanical methods of measurement

It has great advantages in accuracy over a method which has been attempted quite often, namely, using a length of tape, playing it through as a continuous loop and examining it with an ordinary wave analyser, because an ordinary wave analyser has a curved response and there was always a " WOW " on the tape Therefore, the level was never accurate because the mean frequency was continuously changing Consequently, the accuracy would depend upon the resolution that one was trying to use With a third octave, it would not be too bad, but when going down to a tenth octave it would be hopeless

It was surprising, when looking at any wave form, to find out exactly what there was in it Mr DOBSON said it had been his firm's experience to date that there were a lot of established methods which attempted to do this analysis in another manner, because there had not previously been a practical system of carrying out a complete

Fourier analysis with any degree of accuracy at all

He said that he did not understand the point concerning a step function and Fourier analysis He agreed that when introducing a square wave, something else might be seen One did not necessarily want to apply in fatigue testing the wave form observed at the pick-up, but wanted to apply a suitable wave form and to try adjusting its characteristics until it gave the wave form which came out in practice, and then to continue applying that one After all, the nature of the stress that was being applied would be radically modified by whatever member it was measured on

Mr Trumper said that the complex wave form had to be copied with testing apparatus which produced only a simple wave form

Mr Dobson, in reply, said he could not see that it would ever be a retrograde step to know all about it or that it was ever advantageous to know less

The **Chairman** then invited comments from somebody engaged on the design and stress side

Mr V A B Rogers (*Assistant Chief Stressman, Fairey Aviation*), who recalled the point made by Mr TRUMPER, said, that he (Mr Trumper) was concerned simply with the representation of the stress in a simple testing machine, but that among the other aspects was the understanding of what was happening on the actual aircraft One wanted to know as much as possible of the harmonic analysis of the signal from the point of view of the design Harmonic analysis, however, was not so important, from the point of view of the fatigue testing machine provided that the general peak to peak level of stress could be obtained The two points must not be confused

The **Author,** in reply, said it did not seem to be a case of objectively asking what one would like or what one might do He was considering a case in which a flight test had been made and unharmonically related information had been recorded it was necessary to know what that information was from the stressing point of view It is the dynamic load characteristics which have to be considered Consequently, there is no case for not having equipment that will do the job efficiently

As this kind of thing will occur, especially in blades, tail rotors and assemblies of that kind, there must be the means to determine what the load characteristics are

There is no point surely, contending that unharmonically related information should be ignored simply because the average company had not the facilities to determine its full meaning, quickly and simply

The **Chairman** said there was little doubt that there were two sides to the question One wanted to be able to get a full analysis and know where it came from This was important

Mr Shapiro (*Consulting Engineer*) (*Founder Member*), suggested that too much analysis *could* be misleading Firstly, fatigue strength depended on the number of repetitions If, say, a tenth harmonic was found, the nominal number of repetitions was multiplied by ten , but this was not the evidence on which knowledge of fatigue was based It was admittedly a limited knowledge, but it worked primarily on the basis of number of repetitions Harmonic analysis wave shape in the first, second and probably third approximation did not matter in fatigue This had been fairly well established in all the evidence he had been able to see

Secondly, there was one aspect which was purely mathematical Unless the harmonic analysis gave the resolution into harmonics *and* their phase relations, the wave which could be obtained by the recombination of harmonics, gave wrong levels Thus the trace would have been misinterpreted This, therefore, was important

If the harmonic analysis gave phase relations as well as the amplitude of each harmonic, at least there was no misinformation It was, however, even possible to mislead by not giving the full information on phase relations It might not matter much in the tenth harmonic, but it mattered very much in the second and third harmonic, which could be of quite considerable importance in blade stressing

Mr SHAPIRO asked what was meant by " direct calibration " , he had not quite understood it Secondly, what was meant by " direct dynamic calibration " , thirdly, how was the signal for the azimuth angle obtained , and fourthly, was the Author quite sure that the Elliott 10-gauge channel display unit could be made to work accurately, or was it simply an impression which he had acqui ed from limited experience ?

The **Author,** in reply, said he did not wish to stir up the dust on the question of full analysis or otherwise By ' direct calibration,' he meant the difference between actually connecting a strain gauge or a transducer directly into the equipment under static conditions and creating equivalent conditions to flight on a test rig to calibrate the strain gauge or transducer into the equipment directly

Concerning dynamic calibrations, he said it had often been necessary in the past to calculate from a straightforward galvanometer calibration which was virtually a straight line characteristic, or should be, with open circuit voltage which would be dependent on the internal resistance of the galvanometer and several other factors, and referring these factors again to the input impedance of the amplifier which was used, and so on

In this process there could be a certain amount of error Using Saunders-Roe equipment the transducer was directly connected into the equipment and the calibration was done with the very same strain gauge or potentiometer that would be used in flight

Mr Shapiro asked whether this meant calibration directly from stress

The **Author** replied that it did not This method described terms of calibrated load The important thing was that precisely the same strain gauge would be used for calibration and actual tests on the component in the aircraft

His experience of the Elliott-Yates equipment was limited He shared the opinion of Mr Peter Jackson, until recently head of the Electronics Division of Saunders-Roe, that it was no more than an indication of the dynamic stresses It did not bear any relation to the accuracy of the equipment they had developed The Elliott-Yates equipment might have been improved Alternatively, if suitably modified, it could probably be made to function more satisfactorily He did not, however, consider that the equipment in its present form was very suitable as a choice for this type of work

In answer to Mr Shapiro's question concerning the azimuth signal the AUTHOR explained that inside the Beaudouin recorder there were three relays, and attached to each relay was a small mirror All that Saunders-Roe had done in their slip rings was to incorporate one further slip ring in which was an insulated segment Two brushes were mounted, which were more or less just under the width of the segment, so that when the insulated portion was in contact the relay was de-energised and the recorder registered a blip on the film It was known where the segment was in relation to the geography of the hub when the slip rings were mounted, and so an azimuth was obtained in that way

On slide 12 could be seen the pronounced once-per-rev loads with engine orders super-imposed on top The diagram showed the Mk 6 Skeeter in powered flight The record button was depressed sometime prior to the pilot throttling back and going into autorotation The further traces showed the reaction of the strain gauges in the hub in powered flight

Mr C E P Jackson (*Vibration Engineer, Westland Aircraft*), said he assumed that the Author had not yet done any measurements on tail rotor stresses He did not think it would be a proposition to revolve pre-amplifiers on a Skeeter tail Therefore, the Author would have to make the slip rings work when he reached tail rotors Why not make them work on the main rotor as well ?

The **Author,** in reply, said it was a promising suggestion to have pre-amplifiers on tail rotors He did not know what the management would think about any proposal on these lines

Obviously, the short answer was that it was not possible to have them as thermionic amplifiers Up to the present, he had not been responsible for any tail rotor for fatigue testing, and as far as he knew it was not envisaged on the Skeeter aircraft If, however, it was contemplated, his approach possibly to the problem would be to go straight over to transistors He would certainly attempt to do it with transistors rather than in developing the very difficult business of feeding strain gauge information through slip rings

The AUTHOR said that nobody agreed with him in that respect, but prior to his joining the Helicopter Division of Saunders-Roe he had inherited a backlog of information on the failures of endeavouring to do just as Mr Jackson had suggested In fact, about a year ago Saunders-Roe had tried to measure the stick forces in their rotor Test Tower directly with no slip rings It was a complete, straightforward job, trying to measure the reversals of small loads in a shaft Without the facilities of prior amplification they found that drift was a great problem, the loads that they wanted to measure were very small and they had had to give it up in favour of the alleged ' complicated ' technique

The AUTHOR said he still did not think that the high impedance gauge was the complete answer The complete answer, he thought, was sufficient amplication and control over what was being amplified As his traces had shown, in flight, a tremendous range of flight conditions could be covered He cited particularly full power at 335 rotor r p m in the Skeeter aircraft The oscillatory loads in the flapping links were much lower than, say, in cruising at the same rotor revs Without means of attenuation it would be necessary to have two flights or different sets of galvanometers, or something just as awkward

The system they had developed to the present stage had vindicated itself, but it was by no means the penultimate The AUTHOR expressed the feeling that the rotor mounted amplifiers, married to the tape system and automatic analysis, was a technique which would do the complete job most efficiently

Mr Appleton said that for the benefit of those not directly connected with instrumentation, he wished to raise a point in defence of the Author's use of pre-amplifiers on the rotor head If there was a low signal slip ring problem it was sound instrumentation practice to provide pre-amplifiers on the rotor head The only additional precaution was to make quite sure that the additional mass, etc , in no way upsets the dynamics of the hub or system being instrumented

He suggested that the Chairman and any others in similar capacities, who are always pressing for a reduction in the number of test flights especially when strain gauges are being used, should encourage the free exchange of information between instrumentation engineers of the various companies engaged in helicopter work , and secondly, which was perhaps more important, they should discuss their problem fully with the instrumentation engineer right at the start and not half way through the job These two factors will go a long way to providing more suitable instrumentation for the problems in hand, more reliable instrumentation and a much higher utilisation of test aircraft

Mr A J Fagg (*Test Engineer, Strain Gauge Dept , Fairey Aviation*), asked Mr DOBSON what arrangements he made in his analysing for any transients that might occur

Mr Dobson, in reply, said that if it was a transient which was on the record, it would be analysed It would show the separate components but they would be so small that they would not be seen

Mr Fagg explained that he was thinking of something like a gust on the aircraft, causing a change of loading

Mr Dobson replied that one looked at the wave form which was being analysed, marked the chart and said " That is the bit of wave form I have analysed " One selected the chosen part and did not analyse the whole record When the analogue record was presented one could select something which looked interesting or ignore it if it appeared phoney

The **Chairman** suggested that as the discussion appeared to be confining itself to the characteristics of the Mervyn recorder, Mr Fagg might pursue it with Mr Dobson afterwards

Mr Dobson replied that it was a matter of the laws of nature

The **Chairman** said he had been glad to hear about the Mervyn recorder They had had a very interesting lecture on a highly technical, specialised subject, which had evoked an extremely good response and vigorous questioning of the Lecturer's approach There had, however, been an equally vigorous defence The Association was grateful to the Author for the trouble he had taken

The CHAIRMAN expressed his pleasure at the presence of a number of visitors Since the strength of such an Association, dealing with an expanding interest in aviation, was derived from membership, he hoped that some of the visitors would be encouraged to become members, thereby broadening the base and stimulating the strength of the Association The return would be quite beyond their individual contributions It was the aggregate strength which counted

The vote of thanks to the Author was carried by acclamation

WRITTEN CONTRIBUTION RECEIVED FROM MR F R BALLAM

I would like at this time to submit a few more comments for consideration by Mr MACMAHON They may be in part unconnected but apply to various remarks which he made during the lecture and ensuing discussion

I would suggest that providing that his slip ring designs and installations are properly executed then it is merely a matter of correct application of equipment of which a considerable quantity and variety already exists In any event he will finally have to make slip rings work as I cannot believe that even he would be so awkward as to wish to measure torsional vibration stresses or stresses in say blades on an engine cooling fan using his preamplifier equipment or even a transistorised version of it

I cannot in any way understand his reference to " losing the steady components of stress " when using A C energisation Surely the primary object of using carrier amplifier equipment is to simplify amplification of steady and low frequency components of stress

Under the heading " Stress in Rotor Blades," paragraph 5, I would like to ask who on earth wants to reject steady components as surely much more reliable analysis of steady components of stress is possible if the measurements can be made from a permanent record, which can always be referred back to in cases of doubt

In the analysis of several thousands of recordings of vibratory stresses in main rotor blades we have found that invariably the main components of vibratory stress are in an harmonically related series, *i e* , 1st, 2nd, 3rd and 6th, and occasionally 12th rotor orders with some lower levels of 1st and 2nd engine order

All our work to date has been done with carrier equipment (Miller, California Films and Equipment) While we had some trouble with early slip rings, we finally got over this in a matter of some three months of concentrated effort With low peripheral speeds the brush pressures had to be raised to a point where frictional heating became a problem, and blast cooling was resorted to Thermocouple effects, if present at all, did not trouble us as D C voltages are not capable of modulating the 2,000 c p s carrier In any event if full live bridges are used above the slip rings, any such effects should be self cancelling

I attach hereto (see opposite page) a specimen of recording taken from —

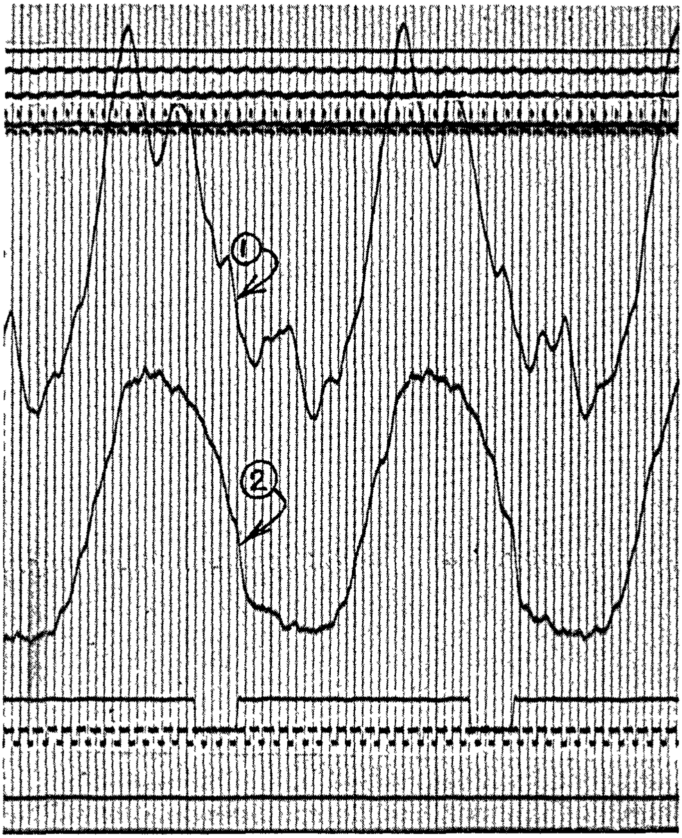
(1) a 2,500 ohm full bridge, and

(2) a 200 ohm full bridge

Here we used our normal carrier amplifier equipment at almost full gain, the signal-noise ratio is obviously very low and has been so, right through the series of tests without any attention *at all* to slip rings This record is picked solely because it happened to be surplus to our requirements and is completely representative of normal waveform quality

MR MACMAHON'S REPLY TO MR BALLAM

I should at the outset like to thank Mr BALLAM for his interesting and most revealing comments I draw some comfort from his statement that " they may be



ın part unconnected " I most definıtely confirm thıs crıtıcısm

Mr Ballam ınfers that there ıs some standard of acceptance for slıp rıng desıgn and ınstallatıon In the helıcopter ındustry, due to the dıversıty of transmıssıon and hub desıgns we know that there ıs not I must assume therefore, that Mr Ballam has only consıdered the hubs wıth whıch he ıs famılıar, ıf thıs ıs the case, then hıs comment ıs a platıtude

I would protest very strongly, ın respect of Mr Ballam's statement, that there ıs exıstıng a consıderable varıety of equıpment for thıs specıalısed type of work I do not doubt however, that there ıs a great quantıty of unsuıtable equıpment It was thıs very sıtuatıon whıch prompted the Mınıstry to place a development contract wıth Saunders-Roe for the desıgn, development and manufacture of a prototype equıpment to a set of standards agreed to by a commıttee of emınent rotary wıng engıneers, who acted ın an advısory capacıty to the Mınıstry I hasten to add, that I dıd not sıt on that commıttee, but from the conceptıon of the development work I found nothıng wrong wıth theır recommendatıons

Consequently, I would suggest that the crıtıcısms now beıng levelled at the prıncıples of thıs equıpment by Mr Ballam and others, smatters of sour grapes, when one refers to the hıghly favourable characterıstıcs of thıs equıpment compared to equıpment now ın operatıon ın other companıes

I regret that I have given the impression of being awkward, this is a National characteristic of the Irish, and I feel that I must have more than my fair share if I have given this impression in such a short lecture I very much regret the introduction of side issues, but Mr Ballam's comments regarding tail rotors and cooling fans do rather come under that heading It must be clearly understood that the Saunders-Roe equipment is for measurement of hub and blade phenomena Tail rotor or engine transmission stresses are nominally outside its scope It must not be construed, however, that I think from a general point of view that this limitation of use is desirable, obviously it is not At the same time, it should not be assumed that should our equipment be required to measure tail rotor stresses that it could not do so

I think it would be a pity to rule out the use of transistors altogether If Mr Ballam cares to refer to any of the more recent manufacturers' technical information, I am sure he will agree that the possibility of their use in such applications is distinctly more favourable than it was six months ago

We must not ignore the new semi-conductor materials that are manufactured as strain gauges, the G E C gauges have remarkably high signal outputs for small dynamic strains On reflection therefore, if confronted with the problem of tail rotor work, I would have three functional alternatives to choose from

There appears to be some confusion regarding my comments in respect of discrimination of steady stress when using A C energisation of strain gauges This is a regrettable feature of equipment in current use, and should be qualified in respect of American equipment, which is, of course, not generally available, unless one is fortunate enough to be connected in some way with an American Company In any case even this excellent American equipment is too heavy and bulky to be carried in small helicopters

If one cares to draw a comparison between the Saunders-Roe equipment and any other equipment available in the United Kingdom, it soon becomes clear that, though functional, it must be precluded for the average user on the grounds of weight and bulk

At the same time, the carrier equipment now being used by Mr Ballam appears to satisfy him, and from what he says, it is ideal for use in helicopters which are able to operate successfully with some 380 lbs of equipment and Flight observer installed in addition to the aircraft's normal requirements, this is to say nothing of C G considerations, when one reflects on the desirability of carrying out all Flight tests in equivalent operative conditions

The findings in respect of the harmonic relation of oscillatory stresses in Westland's blades is most interesting I think it would be unwise for me to assume that the harmonic relation in the Saunders-Roe developed metal blade will give the same desirable feature I base this comment mainly on the fact that there are some differences between the Westland blade and the Saunders-Roe blade in general construction Furthermore, there are flexibility considerations These two facts alone may well upset any pre-conceived philosophy by Mr Ballam, what is good for the goose, is not necessarily always good for the gander

The details enumerated by Mr Ballam in respect of slip rings are interesting I agree with him entirely about the desirability of low peripheral speeds, the technique of forced cooling is also enjoyed by ourselves in specific cases Mr Ballam has obviously experienced trouble with thermocouple effects from slip rings One wonders therefore, what problems beset people endeavouring to operate a direct recording system I would agree with him about its negligible effects to his carrier system, but of course, one strong feature of the Saunders-Roe equipment is its ability to ignore quite large transfer potentials due to thermocouple or differentials in brush contact resistance from slip rings

I was very impressed with the quality of the recording that Mr Ballam has obtained using his equipment I would therefore congratulate him on his endeavours to maintain a high standard of recording technique, this I am sure, is the aim of us all The means by which the ideal can be obtained may vary, this is a fundamental factor in any form of enginerring It is my earnest hope, that the controversial nature of the general discussion will provoke greater interest in the perfection of stress measuring techniques for rotary wing aircraft now being conceived The new designs of aircraft will undoubtedly bring new problems, the successful solution of which is the earnest desire of us all