2 WRBpp

WITNESS SARSTEN: Right.

BY MR. ELLIS:

Q And what were the values at the synchronous speed and at the underspeed?

A (Witness Sarsten) These values were not interpolated. But I can give you the values for 3300 and 3100 kilowatts.

At 3300 kilowatts the value, at synchronous speed, was 6.405 from the calculations. Or, with an amplitude correction, 6.456.

At 3100 kilowatts the values were 6.214 psi and, if we would use the same correction, we would have to correct this, increase it by a figure of 8/10ths of a percent.

Q So, am I correct that at 3300 kilowatts, your calculations show that the 13 x 12-inch crankshaft meet DEMA at the synchronous and underspeed conditions, but not at the overspeed conditions, is that correct?

A That is correct. However, I would like to add that these calculations were based on approximate values for the T sub-N figures. They were calculated on the basis of a series of coefficients given in a German reference book. We had to make both a program to do this -- type in all the over 300 constants employed -- and perform the calculations in the course of a weekend. I would have liked to have had

2 WRBpp

MR. ELLIS: Is it relevant or significant how close to the synchronous speed that critical order is, in terms of assessing the adequacy of the 13x12-inch crankshaft?

A Yes. The closeness of the critical speed will, of course, be reflected in the torsional vibratory levels experienced from the reports, although I have not calculated this myself. The original 13x11 crankshaft was closer to a critical speed and, therefore, experienced higher levels of torsional vibratory stresses than the replacement crankshaft would have received.

Q Professor Sarsten, do you know which was the order that was closest to -- the critical order that was closest to the synchronous speed for the 13x11?

A Yes. I do believe it was the fourth order that was closest to the synchronous speed.

Q And do you know which is the critical order for the 13x12-inch crankshaft?

A The 13x12-inch crankshaft lies between, really -- it lies below a fourth order and is above a five and a half order. There's also a fifth order and a four and a half, but they are less significant.

Q Does the combination of the facts that the critical orders are farther away from the synchronous speed on the 13x12-inch crankshaft and the fact that the

2 WRBpp

orders. And for that purpose, or for a true summation, a computer program would, preferably, have to be employed.

This, as far as I could see, was an approximate summation of the five and a half order and the four and a half order. By taking the square root of the sum of the squares of these two orders-- And I would not like to call this even a summation of two orders. And, again, I'm referring to the fact that only a handcheck, quickly done, was made of these two orders by this approximate method. What ABS uses in their evaluation — complete evaluation -- I do not know. I would assume they would use some sort of a computer program, for this in the year 1984.

Q Well, you don't have any knowledge one way or the other whether this is a complete evaluation or not, do you?

A I do not. I hope it is not.

JUDGE BRENNER: Mr. Ellis, you gave the wrong exhibit, I believe, or maybe I heard you incorrectly. I thought you said County Exhibit 35?

BY MR. ELLIS: I must have. I've written down 35. What's the correct number, Judge?

JUDGE BRENNER: I don't know because I don't have an index list from the County. But 35 is the Franklin Institute Report under cover of the Board notification.

BY MR. ELLIS: Yes, I'll find that number and correct it, if I may. I did not -- I wrote it down

WRBeb

A You just referred to that. The strain gauge read was placed slightly off the position of highest stress. There are curves in the report showing the calculated values of highest stress. One would have to go through these and look at the drawing in order to find out exactly where this is on the crankshaft. I have not done that in detail.

Q You don't have any information then about where the highest stress experienced in the 13 by 12 inch crankshaft that is any different from that that is reflected in the FaAA report. Is that correct?

A That is correct. They did not go into detail here.

Q And with respect to the Goodman diagram, your testimony then is that the finite element analysis was only used in connection with the location of the strain gauges. Is that right?

A No. It also calculated the stress levels.

Q Is that for the Goodman diagram, the finite element was used to calculate the stress levels? Is that your understanding?

A No. As I remember, the finite element calculations calculated the stress levels in the crankshaft, in torsion and in bending, but this did not give the true values. In one way it only gave perhaps bound values for these stresses.

1 WRBpp

measurements that was referred to previously in the testimony of Chen, where he referred to the Stone & Webster report.

I have, however here, used the value of .693 degrees as given by Failure Analysis Associates in their report.

Q You also used the T-sub-n or forcing function values used by FaAA. I take it, therefore, you are satisfied with the accuracy of those T-sub-n values used by FaAA?

A No, actually I am not completely satisfied with the T-sub-n values used by Failure Analysis Associates. I would consider them a lower bound on the true values.

I will explain why.

Initially, let me say that probably the error is not very large and, therefore, I have not addressed it before. The report from Failure Analysis Associates mentions the fact that the mechanical efficiency is 100 percent according to their measurements, while it should actually be 88 percent. This, I think, was addressed in a previous testimony also.

Let me here give a slight history and explanation of what this is all about, since it reflects on accuracy of the calculations. Normally, the pressure is measured inside the cylinder by appropriate transducers, and the turning

1 AGBeb

JUDGE BRENNER: Let's go back on the record.

Mr. Ellis, complete by eleven o'clock. I'm serious.

MR. ELLIS: I know you are.

JUDGE BRENNER: Okay. Your chuckle seemed to doubt that.

Go ahead.

MR. ELLIS: I don't doubt your seriousness. My chuckle was....

BY MR. ELLIS:

Q Professor Sarsten, your conclusion of a front end amplitude of .69 agreed very closely, didn't it, with the Stone and Webster measured front end amplitude of .693?

A (Witness Sarsten) Yes, it did agree very closely.

Q And what, in your view, does that reflect with respect to the T-sub-n's that you used?

A That reflects, among other things, that the total impact of the T-sub-n values are not unacceptably far off the true values. And again, as I previously stated, the fact that it was lower -- the front end amplitude calculated was lower slightly than the front end amplitude measured indicates that the T-sub-n values may represent a lower bound.

We must again remember that there is a certain

1 AGBagb

Q Thank you, Professor Sarsten.

On page 13 of your testimony you refer to the crankshaft analysis performed by Failure Analysis; to be precise on the bottom of page 12 and carrying over to page 13.

A Yes, I see that.

Q And my question is you have stated that FaAA concluded that the stresses meet the DEMA recommendations on the basis of their modal superposition analysis, is that correct?

A I am just referring to their results, I do not agree with them.

Q What were the results that FaAA -- what were the values that FaAA obtained using its modal superposition method?

A I do not have the exact figures available. They were slightly below 7000 psi over the complete speed range.

However, I must also add that they used a modal superposition which in theory is not applicable when damping is present, at least not unless you place very severe restrictions upon the damping. However, for practical purposes, I would still accept with slight damping that a modal superposition would be correct to use, I would not argue on that.

However, we must again realize that there are

1 AGBagb

a, shall we call it, filtering or factoring out of the amplitudes of the individual orders from the front end measured curve.

Q Is that a modal superposition summation?

A The figures -- I would have to refer to... The figures to the right here from -- Let me get this straight now what this refers to.

JUDGE BRENNER: You had better ask him a foundation question as to what he knows about this table, Mr. Scheidt, because you're off asking him questions on the assumption that he's familiar with what it represents.

WITNESS SARSTON: There are very many tables. I would have to look back and see what they come from to really answer directly, that's my problem.

Could you refresh my memory as to what the figures --

JUDGE BRENNER: He's going to decide what he wants to ask you next.

(Counsel conferring.)

BY MR. SCHEIDT:

Q Professor Sarston, do you know whether the values that appear on the right-hand side of Table 2.5 in Exhibit C-17 are derived from FaAA's modal superposition analysis?

A (Witness Sarston) From what I remember, these are calculated by Failure Analysis Associates based on the

1 AGBagb

WITNESS SARSTON: May I proceed?

JUDGE BRENNER: No.

MR. SCHEIDT: Judge Brenner, may I ask him if he does know?

JUDGE BRENNER: Surely. I didn't mean to cut off the line of inquiry.

BY MR. SCHEIDT:

Q Professor Sarsten, do you know why the values differ?

A (Witness Sarsten) I must state this: there could, of course, be some errors in the program itself. I cannot say that without going through the program.

But based on the assumption that there are no errors in the program, then the differences can be in part attributed to two things: one is the value of damping employed, which is I believe a relative damping of 2.5 percent which is rather large, it gives -- not exactly, but roughly a dynamic magnifier of 20 or lower: and, secondly, it's the use of the modal superposition method and distributed damping which is slightly inaccurate but I would say nevertheless acceptable for these calculations if you do not want very, very extreme accuracy.

JUDGE BRENNER: Professor Sarsten, speaking for myself, it doesn't help me unless you tell me specifically what FaAA did that you didn't do or what FaAA did different

1 AGBagb

than what you did or what you did and what FaAA didn't do in very specific terms.

WITNESS SARSTON: We may end up in a treatise again, Judge Brenner, but I'll try to do my best.

The method used by Failure Analysis Associates employs a so-called modal superposition where the node shape or vibratory shape at each natural frequency is calculated, the excitation of that specific frequency is calculated and the effect of these nodes are then summed to give the answer.

However, if there is damping present to a significant degree or damping is not distributed rather evenly through the system, there will be changes in amplitudes between the masses, a slight twist in the vibratory shape which accounts for a slight inaccuracy.

My method and the method also used by Dr. Chen, I believe -- even though it is referred to as a modal superposition -- takes and calculates the true vibrations of the system, taking the damping into account -- the damping may be arbitrary, it does not affect the validity of the calculations; however the computational effort required to do this may be somewhat larger than when a modal superposition is assumed.

I must also add that I believe from the testimony that Failure Analysis Associates has used the one node

I AGBagb

vibratory form as a basis for calculating their stresses. This is a very good near approximation but not quite exact.

JUDGE BRENNER: Well for example on that last point what specifically did you do that I should contrast with what FaAA did and which one is more accurate in your view and why?

WITNESS SARSTON: Definitely if damping is present the method that I employed is — and others -- is more accurate than modal superposition. If no damping is present the result should be exactly the same, provided that the true vibratory form is employed and not a one-node approximation.

JUDGE BRENNER: A few times in your immediate answer and the previous answer, when talking about damping in connection with what FaAA did, you used words like "if" damping is present and something "may" be this or "may" be that. Tell me what you know about the presence of damping in the real world case and how that is reflected or not reflected in FaAA's analysis and in your analysis.

WITNESS SARSTON: There is damping present. I have been inaccurate -- English is not my native language -- I should say "when" damping is present. There is always damping present. And it is often reflected by the term "dynamic magnifier."

There I have used values of 40 and related them

1 AGBagb

WITNESS SARSTON: You're right so far.

JUDGE BRENNER: So clearly this isn't one of the things you should have included in your answer to explain why it is that FaAA and your result differ, is it?

WITNESS SARSTON: There is a slight inaccuracy, here, yes, perhaps --

JUDGE BRENNER: Tell me the important things about what I should look at in trying to compare your analyses and result with FaAA's result so that I can figure out who's right and what the benchmark is in part which would better represent the real world experience of these engines?

WITNESS SARSTON: The real world experience of the engines is best reflected by a method of calculation where damping is present and where the damping can be arbitrarily distributed throughout the system, not a modal superposition.

But I also said that the errors are not great. The difference between our calculations -- results are less than 5 percent, 4.5 percent as I recall. But I would regard my figures as being the more accurate ones.

JUDGE BRENNER: And what's your basis for your last statement?

WITNESS SARSTON: Because the method employed is, in theory at least, more accurate.

1 AG3pp

Q Does your calculated value of free end amplitude suggest that your calculations are more consistent with the real world than FaAA's?

MR. ELLIS: May I have that question read back please?

MR. SCHEIDT: I, perhaps, can rephrase the question and make it more complete.

JUDGE BRENNER: All right.

BY MR. SCHEIDT:

Q Does the fact, Professor Sarsten, that your free end amplitude calculated value corresponds more closely with the measured value? Does that fact suggest that your calculations are more consistent with real life stresses on the shaft than FaAA's?

MR. ELLIS: I object. I think that was asked and answered. I may be wrong, but I think it was.

JUDGE BRENNER: I thought it was also, although, in the context of the Tn values and the input to get those results. But, I will allow it again just to err in that direction, since the terms were changed slightly.

WITNESS SARSTEN: Yes, I would say so. But I must also add that the discrepancy or difference between our results is not very large, in all fairness. But again, we are here discussing compliance with 7,000 psi and the calculated results are very close. Some small differences

1 AGBpp

completely different calculation.

JUDGE BRENNER: Do you have a view on that question?

WITNESS SARSTEN: My view is we do not know. We've stated that the evidence, in our view, is inconclusive at the load of 3,500 kilowatts.

BY MR. SCHEIDT:

Q Did you attempt, in any way, to verify the accuracy of the Tn values used by FaAA -- I should say the gas pressure measurements obtained by FaAA and put into the Tn values?

A (Witness Sarsten) I have separately, in another context, calculated the gas pressure values for this engine, assuming certain facts about the nozzle holes and other things. But I did not compare the measured values with these calculated values of the gas pressure diagram obtained by a computer program. So the answer must be, no, I have not. But I have previously today, referred to approximate calculations done in another context using the MAASS formula.

Q Those are the German Tn values referred to?

A You can refer to them as the German Tn values. But again, these values will vary slightly with the input used in the program. And I could not verify exactly the T-sub-n values employed by Failure Analysis Associates.

1 AGBpp

familiar with the European community. Now, Mr. Henriksen is a former employee for a very long time with a member of DEMA and, in fact, has made contact with individuals who he knows to be high in the management of other DEMA manufacturers, those who are personally known to him.

JUDGE BRENNER: You're going a lot further than that question and answer went, I can tell you that.

MR. GODDARD: I think he can provide the answer to that. And this is material which he, as a professional engineer, could rely upon in determining how to interpret the DEMA rules himself.

JUDGE BRENNER: Mr. Goddard, do you see any distinction between an expert knowing what the practice is by other experts in the area, as opposed to having to call somebody up and saying tell me what you do, and then coming here and telling us what that out-of-court declarant, in a phone call no less, told the witness and then relating it to us?

MR. GODDARD: Judge Brenner, the Staff would concede it is clearly hearsay. But it submits it's the kind of hearsay on which an engineer would rely in the evaluation of the DEMA rules.

JUDGE BRENNER: Your buildup in your comment was that here's somebody who knows what the practice is, and Mr. Ellis was questioning about the practice. And I'm

1 AG3pp

asking you isn't the knowledge of the practice different than what I could do.

I could call somebody up and say, tell me what you did. And then I can come back before you and say, gee, this is what Joe said he did. And it's a phone call. So the first time you ask me about, well, did Joe mean he did it for this or just for that or for all the things, I'll have to say, gee, I didn't ask Joe that. Or I don't know.

And being a -- it's rank hearsay, it's not just hearsay.

Give me a moment.

(Brief recess.)

MR. GODDARD: Hearsay is hearsay, in the opinion of the Staff.

JUDGE BRENNER: Well, you're wrong. Because when it gets far removed I get concerned, anyway, I don't know if you do. When it's based on a written document, sometimes there are even problems there. When I can see there are problems of context and interpretation. And now you're basing it on a phone call.

I don't even know if he heard the speaker correctly, although, that's a somewhat different point.

MR. SCHEIDT: Judge Brenner?

JUDGE BRENNER: Give me a moment.

(Board conferring.)

1 WRBpp

the figure.

Q Could you check that from your Exhibit 1, the fourth page?

A Let me define your question. I think you are referring to the chamfer on the inside of the bearings, from bearing shell to bearing shell, is that correct?

Q That's correct.

A I interpreted the rules as using the dimensions from inside a bearing to inside of the opposing bearing, if I remember correctly.

Q Does that take into consideration the one-eighth inch chamfer?

A I would have to go back into the figures, but I do not believe it takes the chamfer into consideration, only the edge of the bearing.

Q Professor Sarsten, do you have calculations that are documented that you can determine whether you took the one-eighth inch chamfer into consideration?

A I might be able to reconstruct this. I would have to go home and also look at the drawings. I cannot state it here and now, I'm not sure. That's all I can say now.

Q Professor Sarsten, is your interpretation of the ABS formulas relating to scaling or dimensions of the crankshafts, based solely upon the deposition testimony of

2 WRBpp

says one of my colleagues handled that, but maybe that's not the case here.

Give me one moment, will you, then I'll see-if we need to hear from other counsel on it.

(Board conferring.)

JUDGE BRENNER: We're going to deny the motion to strike. It is acceptable for an expert to rely on a source such as what the ABS said in that deposition under the Federal Rules of Evidence, I guess it is 703, as well as general precepts of use of expert testimony at our hearings. But even in a Federal court, I think it would be permissible. We will evaluate the weight of it based on how controversial the evidence in the record aduced before us shows this point to be. And if there is a void in the record we will draw the, hopefully, correct conclusion from that void, remembering our caution as to what we're going to do with interpretations. Well, with what the ABS person said in the deposition, is the way we put it. We'll evaluate questions on interpretation of the rules depending on what these witnesses know or don't know about the rules.

So you can ask questions about it, but we won't strike it.

I also think, as a make-weight, that there was no reason why you could not have filed that motion on a timely basis after the Staff filed its direct testimony. But that

1 WRBpp

side.

Then you need the rpm at which the calculation is to be performed or, if you wish, to perform a set of calculations, the speed range, the stepping speeds and so on.

You also need to specify which of the masses are cylinders and the phase angle between the cylinders, which is reflected in the firing order of the engine.

You also need the T-sub-n values, 24 of them is normal, and their respective phase angles, again 24.

You would also want to specify if it is a V-engine or not, if you want additional excitation of any masses and so on, and how much printout you would require. But this is not essential for our discussion.

JUDGE MORRIS: The T-sub-n's are derived from measurements?

A The T-sub-n's are -- may be derived from measured values as in this case. One is not always that fortunate and has to take T-sub-n values from the listings in the literature or from idealized cycles.

There are now available good approximate methods for calculating the T-sub-n values.

Q And the phase angles are determined from geometry?

A The phase angles are determined from the Fourier analysis of the turning moment. You get the results out

1 WRBpp

have to take into account the so-called secondary resonance or the parametric excitation of the distant motion for the inertia forces of the piston. But normally this is of no concern in four-stroke engines. And it usually shows itself only on special occasions when the special order is near resonance and it doesn't apply here. So I would say the results -- the input here is sufficient for the calculation in this case.

Q I believe you answered the County before that a misfiring cylinder would not concern you. Could you explain that a little bit more to me, why that is not a concern?

A The misfiring of an individual cylinder is often required by the classification societies, if there is concern that this would greatly increase or substantially increase the vibratory stresses.

Normally, a misfiring will not last forever. And even though the stresses are slightly increased, the system can usually take care of it.

The misfire of a cylinder is especially important in certain configurations of V-engines where there is a delicate balance between the exciting forces on the two V-banks. And the stresses may arise greatly if this delicate balance is lost and you are in or near a critical order.

It's also important if you have flexible

1 WRBeb

Q In the Delaval straight-8 engine, if there were a cylinder misfiring, how long would it take to detect that?

A That should be detected immediately if there is anyone near the engine. If it is misfiring, you can hear it, you see the exhaust temperature goes down and everything.

It may, for example, happen from an eruptive fuel line and you will certainly see the fuel spray around. So that is not normally something that should go undetected in a manned engine room.

We speak today of unmanned engine rooms where no one is there in the vicinity or checks the readings of the instruments.

Perhaps Mr. Henriksen would like to elaborate.

A (Witness Henriksen) Almost immediately it would be noticeable in the exhaust readings in the control room.

Q With respect to the computer program COMHOL, has there been the equivalent of what I will call a qualification of that program, a benchmarking? And if so, what is the extent of it?

A (Witness Sarsten) Yes, there has been an extensive benchmarking of the program and as time goes on, you compare your calculations to other values and you see that when the same input is used, they coincide very well.

I can name some of the benchmarkings used.

1 WRBeb

A Because of the wide experience they have in this. The large number of cases this is based upon.

Q Well, I think we have overrun our normal breaktime. Let's break at this time for 15-minutes, to come back at about five minutes to four.

(Recess.)

3 AGBpp

BY MR. ELLIS:

Q Professor Sarsten, you were asked some questions about the T-sub-n's and frontend amplitudes. Is the safety factor that is calculated by FaAA's as reflected in 313 depend on either the T-sub-n's or the frontend amplitude calculated by T-sub-n -- calculated by FaAA or used by FaAA?

A (Witness Sarsten) I would have to find the figure, it's figure 313?

Q Exhibit C17, figure 313.

JUDGE BRENNER: Professor Sarsten, it is the Goodman diagram that you were asked about earlier with respect to fatigue safety factors. Do you have it?

WITNESS SARSTEN: No, it is my understanding that the calculated torsional stresses do not enter into this. this is based, I believe, upon the measured values.

MR. ELLIS: You were asked some questions about table 2.5 at 2-11. Would you look at that, please?

JUDGE BRENNER: Still in Exhibit C17?

MR. ELLIS: Yes, sir. Still in Exhibit C17.

WITNESS SARSTEN: Yes.

BY MR. ELLIS:

Q I believe you told Mr. Scheidt that you thought the figures in the righthand column were based on the modal superposition model, is that correct?

A (Witness Sarsten) That is correct. They are

3 AGBpp

calculated from the torsiograph test.

Q Well, the torsiograph test is not the modal superposition, is it?

A I realize that.

Q So would it be fair then to correct your testimony to say that the figures in the righthand column really aren't related or don't have anything to do with the modal superposition?

A The shear stress figures given you here must, if calculated from the frontend amplitude, must be based upon a torsional vibration. A half peak-to-peak figure here is given, which I assume is for the sum of orders. I must admit that these exhibits are not always clear in this respect, but this is the way I have read the table.

Q Professor Sarsten, you were asked a number of questions in which you indicated that the difference between the frontend amplitude that you used and FaAA used, was between four and five percent. Isn't it also true that the differences in your predicted summed stresses, and the FaAA summed stresses, was even smaller than four percent?

A I have not looked into the comparison; it may be.

Q Well, your figure was 7.068, is that correct?

A That is correct. That is the calculated figure, but not corrected for frontend amplitude.

Q That was your predicted figure?