RAC Product Design
Prof. Sanjeev Jain & Bhupinder Godara
Department of Mechanical Engineering
Indian Institute of Technology, Delhi

Lecture – 13
Vibration and noise issues in railway AC systems

All right so, Investigations into Vibration Induced Failures of Refrigerant Connectors in Mobile A.C. Units, this was a case study that was presented somewhere 1995 and there were 2 key faculty members from IIT Delhi who helped close the gap as I said what I did not know about vibrations, analysis, resonance and all that I learnt on the job.

So, we had Dr. Tandon; Industrial Tribology Machine Maintenance so, we used to call it ITMMEC short form and Dr. K Gupta of course, I continue to often meet him. So, the way we split this project was to get the analytical part done in IIT Delhi and we wanted to do the experimental part in the company. So, that we could have a quick resolution and you would not believe it the cost of this consultancy project at that time was just 25000 rupees unbelievable right.

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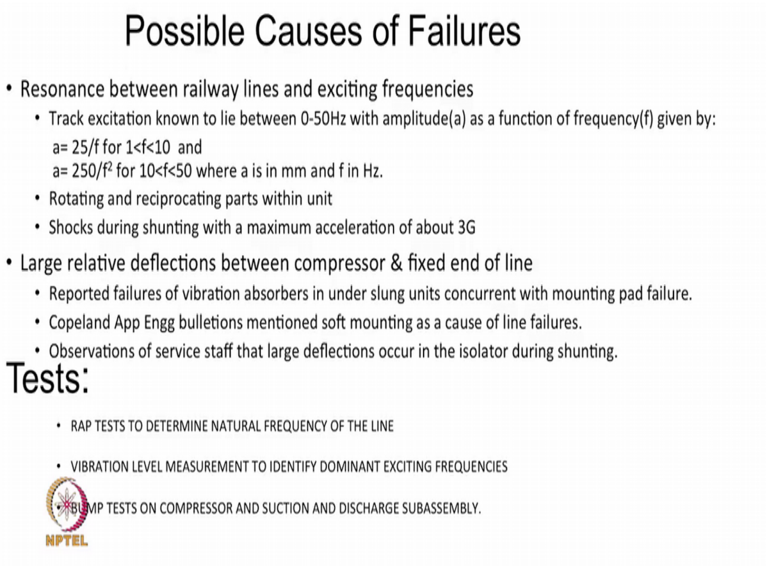

So, the failures that we were encountering were in 2 parts of the AC unit, one was on the suction line so, I had showed you a flexible connector or braided connector.

So, we would have a failure on the third bellow every time in the suction line that was a major one and then the discharge lines are failing as well and they were not failing as repetitively, but they were having failures. So, when we started looking at the whole problem from a vibration perspective there were 2 important things, one was what happens when there is shunting shock and the second was what happens when there is resonance.

So, so far we have been focusing more on the thermodynamic aspects of a product design. So, we looked at coils, we looked at compressors, and looked at cooling and we looked at real life application then we also have to consider what happens with the rotating components and what happens due to shock from the truck. So, these were the 2 things which were simultaneously interacting with the both tubes.

So, the track during train movement is known to have frequency of excitation between 0 and 50 Hertz, with amplitude as a function of frequency given by a is equal to 25 1 f. This was something available from railway aspects as well as it was common knowledge from other countries that have looked at similar problems.

So, when the frequency is between 1 and 10 it is 25 upon f when it is between 10 and 50 and it is 250 upon the square of f the frequency. Now large very large relative deflection between compressor and fixed end of the line would result in problems and then I had to do some research and reference with other countries using hermetic compressors and railways. So, one of the things I found was in an application guideline that Copeland discovered flexibility of the compressor mounting as one of the reasons for deflection; large deflections.

So, to verify this we did one experiment. So, we did an experiment where we made a sub assembly and the sub assembly was one part of the AC unit.

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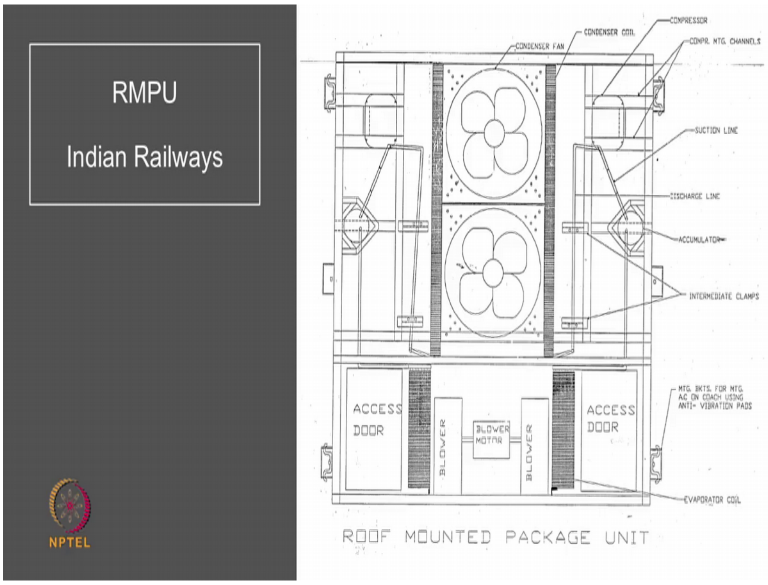

So, if you see the compressor here it is connected in there was a failure happening at this place. So, we just made a sub assembly of this portion we connected the same braided connector to the compressor and we subjected it to repetitive shock. So, they were the defense equipment which was used for validating defense units for conditioning we use the same one the sub assembly and we had this unit lifted up and suddenly dropped repetitively with the compressor weight.

And in about 2 hours of repetitive tests we could replicate the exact same failure that we had during running of the train. So, the braided connector was exactly failing at the same point and then we had confidence we had a means of saying that yes we know the root cause of failures. So, the way to address that was to change the mounting of the compressor so, I am going to show you the details of changing the mount of the compressor.

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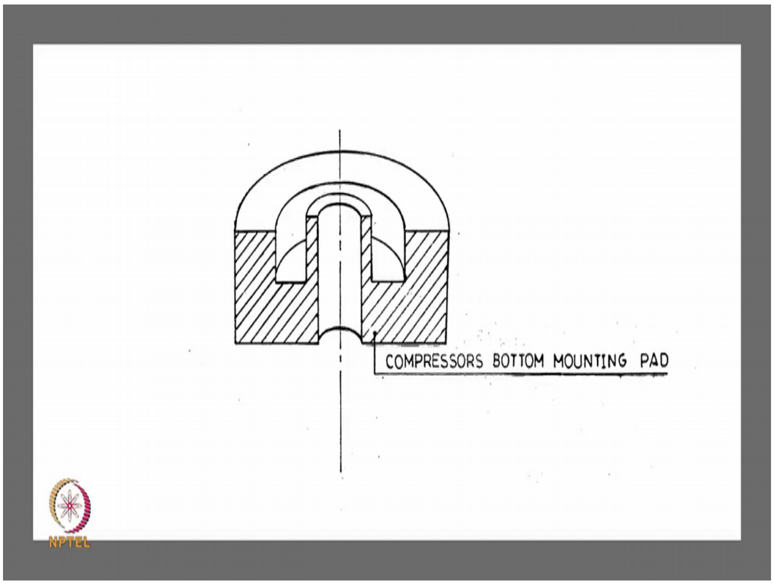

So, this is typically how a compressor was being mounted with a flexible mounting pad and all we did was we replace this with metal. So, that the relative movement of the compressor with respect to the rest of the unit was controlled and then we put it to the same test. So, the same bump test for the same duration and we cleared it without any problem. So, the issue then comes up what happens to the vibrations from the unit to the coach.

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Rubber.

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See the intention of using rubber was that if you use it in a commercial unit stationary application, you do not want the vibrations of the compressor to go to the building to the foundation so, it was provided with that perspective.

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Yes, it would eliminate the transmission of vibrations from the compressor body to the frame where the compressor is mounted. So, here in the railway unit there was another mounting pad which was used between the frame of the unit and the railway coach body. So, that was isolating the vibrations from the unit so; that means, fans, blowers, compressors, everything. So, the function was being done through another set of pads which were isolating the entire unit vibrations from the coach.

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It was actually an oversight in the design that we picked up a stationary application compressor we put it as it is and it worked fine in a certain stretch. So, the root causes if we get to was that the quality of track between Delhi and Bombay was very different from the quality of track between Delhi and Amritsar. So, the number of shocks that the unit was being subjected to was different and another thing we found was that while there was a spec which was there with railways the spec there was no way to verify that the spec actually reflected the rail vibrations.

So, when we took that up with RDSO they were also considering means of a verifying that and then there is a major issue, because if you find that you are not complying respect then the entire warranty that different manufactures would give to railways would end up being scrutinized. So, this is something which is still unanswered and one indirect answer that I got was later on after this project was done and there was a contract between a German company and railways for new coaches. They introduced those units and those units had compressive failures and the compressor failures were inside the compressor.

So, there is tubing inside the compressor, there is a motor and mounted on springs and they had repetative failures and knowing my background they consulted me and they asked me. So, I said look you already have the means to do this I mean for me to just step in and simply look at your system and give you an input is not possible, but that was that meant there was a challenge. There was a challenge between what was straight another spec because Germans would typically test to spec and assume that the spec is covering with a requisite factor of safety the entire field condition.

So, it indicates that the field condition is different maybe different, but you cannot say for sure unless you measure it. So, this took care of one set of problems and this did not require so much of vibration analysis as it required doing a pure mechanical verification using bump tests. So, where did this knowledge on vibrations come in handy.

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2.1.2.RAP TEST ON DISCHARGE LINE

The discharge line was tested with flexible reinforced tubing and the same geometric configuration as in the failed units. Then it was tested with intermediate clamps as shown in figure 1. Change in mounting from flexible to rigid was also checked for its influence on the line natural frequencies.

TABLE 2
Natural Frequencies of Discharge Line with vibration absorbers

S. No.	Compressor Mounting	Intermediate Clamps	Direction of Impact and Measurement	Natural Frequency
1	Rigid	No	Vertical	85.5, 107.5
2	Rigid	No	Horizontal	47,104.5,135.5
3	Flexible	No	Vertical	87.5,101
4	Flexible	No	Horizontal	49
5	Flexible	Yes	Vertical	58,136,254.5
6	Flexible	Yes	Horizontal	46.5,93.5,111,128
7	Rigid	Yes	Vertical	57.5,137,264
8	Rigid	Yes	Horizontal	95,111.5,131.5

So, we did something called a rap test. So, have you ever heard of a rap test so, let us say I hit this it vibrates. So, this is closest demonstration of a rap test. So, you have a tube, it has a natural frequency to get to the natural frequency you excite it and then leave it to vibrate and you measure that frequency.

So, the discharge line failures that we were experiencing were on account of resonance, but to get there we had to experimentally validate it and do some measurements. So, this was an area which as I said before was something which I learnt on the job. So, when we had Professor Gupta and Dr. Tendon come in they came in with the vibration measurement oscilloscopes and we mounted those and checked different directions of a vibrations.

So, what was the natural frequency into perpendicular directions and we found them to be matching with the second harmonic of the compressor excitation frequency. So, are you able to read some part of this or I will read it out for you if it is; the discharge I was tested with flexible reinforced tubing in the same geometric configuration as in failed units. Then it was tested with intermediate clamps as shown in figure 1 and I will show you the figure 1.

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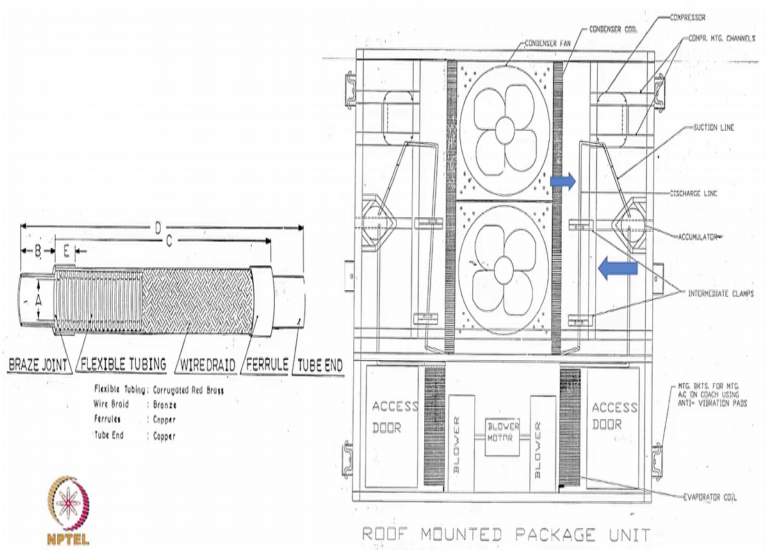

FIGURE 1

So, this particular connector was used also in the discharge line which is over here and this figure actually shows the modified units. So, before this modification was done with the clamps we had looked at this braided connector. So, what we did was, we put the unit exactly as is and looked at the natural frequency of excitation. And then you can see different cases where the compressor mounting is rigid in the first 2 cases there were no intermediate clamps. So, some of the easy shortcut solutions without doing a vibration analysis was to just hold the pipe better and we will add result in a preventing failures and that unfortunately was not resulting in preventing failures.

So, these measurements indicated that the natural frequency was 85 and 107.5 for one direction which is vertical and then for horizontal direction we had 47, 104.5, 135.5 and then we made tests using a flexible mounting of the compressor and we found that there was a small no not very significant difference on the natural frequency. So, the discharge line failure it seems was apparently not because of anything to do with the mounting it was to do with resonance.

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Natural Frequencies of Discharge Line with vibration absorbers

S. No.	Compressor Mounting	Intermediate Clamps	Direction of Impact and Measurement	Natural Frequency
1	Rigid	No	Vertical	85.5, 107.5
2	Rigid	No	Horizontal	47,104.5,135.5
3	Flexible	No	Vertical	87.5,101
4	Flexible	No	Horizontal	49
5	Flexible	Yes	Vertical	58,136,254.5
6	Flexible	Yes	Horizontal	46.5,93.5,111,128
7	Rigid	Yes	Vertical	57.5,137,264
8	Rigid	Yes	Horizontal	95,111.5,131.5

1. From the observations in S.No. 2 and 4 there is a resonance between first harmonic of compressor excitation and the natural frequency of the discharge line. This is the most probable cause for failure in the discharge connector.
2. From observations in S.No.1,2,3 and 4 it is also clear that the compressor mounting has very marginal effect on discharge line natural frequencies.
3. Records in S.No. 5 and 7 show that by providing intermediate clamps, the first mode of natural frequency is well placed away from the first harmonic of the compressor excitation frequency of 47-49Hz. The second mode of natural frequency of 133Hz could give a resonant condition with the third harmonic of the compressor excitation frequency.

So, the first harmonic of compressor excitation and the natural frequency the discharge line is was considered as the most probable cause of failure and then fear a look at observations from 1, 2, 3 and 4 it is also clear that compressor mounting has very marginal impact on discharge line natural frequencies. Now how many of you understand the second harmonic off the compressor excitation frequency? So, the compressor motor is running at a 50 Hertz.

So, the first harmonic would lie at 50 Hertz plus or minus 3 Hertz because there would not be an accurate frequency on the train and the second harmonic would be at a somewhere between 90 and 100 or maybe 85 and 100 and that is what these tests were pointing to 87.5, 101, 136 third harmonic.

Now, if we put in clamps; which is serial number, 5 and 7 flexible mounting with the clamps the first mode of natural frequency is well placed away from the first harmonic of a compressor excitation frequency. The second mode of natural frequency could give a resonant condition with the third harmonic of the compressor excitation frequency. So, the crude method of just putting a clamp was not resulting in enough separation between the compressor excitation frequency first harmonic, second harmonic, third harmonic and the natural frequency of the tube.

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Natural Frequencies of the compressor

S.No.	Compressor Mounting	Direction of Impact and Measurement	Natural Frequency
1.	Flexible	Vertical	12.5
2.	Flexible	Horizontal	8.0
3.	Rigid(*)	Vertical	16.5,29.0
4.	Rigid(*)	Horizontal(Transverse to suction line)	16.0,29.0
5.	Rigid(*)	Horizontal(along the suction line)	27.5

* The compressor had two additional flexible mounts at the top.

The results in Table 3 clearly show the increase in Natural Frequency of the compressor on change to a rigid mounting. This is desirable since the track excitation has low frequency components with a relatively high amplitude.

2.2. MEASUREMENT OF VIBRATION LEVELS

The vibration levels were checked for the three parts i.e. the compressor, the suction line and the discharge line. For this purpose the unit was put to normal operation. An accelerometer (B&K 4371) was mounted at different location and the steady state overall amplitude was measured using a storage oscilloscope (Kikusui DSS 6520A). The accelerometer signal was amplified using a charge amplifier (B&K 2635) or vibration meter (B&K 2511). An instrumentation tape recorder (Teak 101T) was used to record the steady vibration signals. A frequency spectrum analyzer (B&K2032) was used to carry out the frequency analysis to provide information about the relative contribution of the various excitation frequencies. Two typical spectra are shown in figures 5 and 6.

Then we had the frequency natural frequency of the compressor, the compressor is also floating on the different mounting. So, looking at this again we find that the compressor mounting whether we change it from flexible to rigid we still keep the natural frequency between 16 and half and 29. So, the compressor natural frequency can increase because of rigid mounting, but it is still not away sufficiently away from the 0 to 20 Hertz.

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TABLE 4

Vibration Levels (rms velocity mm/sec) on Suction Line with Absorber

S. No.	Compressor Mounting	Direction of Measurement	14 Hz	22.5 Hz	1X	2X	3X	Overall
1	Rigid	Vertical	1.0	2.5	6.0	1.0	4.5	10.3
2	Rigid	Horizontal	1.5	5.0	14.0	2.5	4.0	19.8
3	Flexible	Vertical	0.5	2.0	11.4	1.5	-	14.3
4	Flexible	Horizontal	2.0	5.0	20.0	1.5	5.0	25.8

In the next part was while there is vibration and there is excitation of the compressor and the lines what is really going to happen, how strong is the impact, whether is going to lead to failure not for that we have to look at the displacement. So, how far does the tube move because of these match between the natural frequency of the compressor and the natural frequency of the tubes and the impact because of the first second and third harmonic that is coming in because of rotating parts and was primarily the compressor. So, this page here gives details of what all equipment was used.

So, we use an accelerometer and then that time BNK4371 was the accelerometer that was available, the unit was put to normal operation and a steady state overall amplitude was measured using a storage oscilloscope again the model number and all that is given here. The accelerator signal was amplified using a charge amplifier or vibration meter and instrumentation tape recorder t 1 0 1 t was used to record the steady vibration signals and then we had a frequency spectrum analyzer to carry out the frequency analysis.

So, you know the reason why I was not one into vibrations because it is so, complex right was used to carry out the frequency analysis to provide information about the relative contribution of various excitation in frequencies. So, this and then the spectra of those are shown in the I will show you in the next figures, but here we have the measurement of a different displacement levels which is RMS velocity millimeter per second on the suction line with the absorber.

So, we have 4 cases rigid mounting 1 and 2 flexible mounting 3 and 4 and then the displacement direction vertical and horizontal and what we find is that the displacement goes up to 6 millimeters per second at the first excitation frequency and the overall displacement is 10.3 and the maximum of 25.8.

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In Table 4 the high frequency components of the response signal are not included because of their extremely low amplitude. The following observations can be made from this Table.

1. The response is predominant at 1X (45-49Hz) and a little less at 3X. This is expected because the compressor has three cylinders.
2. Vibration levels are lowered on account of change of mounting from flexible to rigid.

In the absence of any standards the values of the vibration levels have been used only for comparative purposes. The values also establish that the compressor is the predominant source of vibration among the rotating equipment mounted on the frame. In view of this only the 1X and 3X excitation frequencies are considered for further analysis.

Now in table 4 the high frequency component of the response signal are not included because they were very low and they were not resulting in any significant impact on failures which was the primary objective of the study.

At 49 Hertz 45 to 49 Hertz and slightly less at the 3 X which is in the 133 Hertz range. Now why is it that 3 X is becoming important? So, the compressor that you are using had 3 cylinders so, the third cylinder means there would be a certain vibration peak at 3 X of the frequency this again with something which was a learning.

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2.2.2. VIBRATION LEVELS OF THE DISCHARGE LINE

The results of measurements of the discharge line with absorber are given in Table 5

TABLE 5
Vibration Levels (rms velocity mm/sec) on Discharge Line with absorber

S. No.	Compressor Mounting	Direction of Measurement	14 Hz	22.5 Hz	1X	2X	3X	Over-all
1	Rigid	Vertical	-	5.0	35.0	4.0	23.0	45.7
2	Rigid	Horizontal	-	3.0	77.0	-	19.0	87.0
3	Flexible	Vertical	1.5	4.0	38.0	32.0	10.0	53.0
4	Flexible	Horizontal	-	-	134.0	7.0	28.0	144.0
5	Rigid(*)	Vertical	1.5	3.0	14.2	-	9.5	23.1
6	Rigid(*)	Horizontal (+)	2.0	4.0	40.4	3.0	33.0	57.4

Readings in S. Nos. 5 and 6 are with intermediate clamps in the discharge line.
The following observations are made from the results of Table 5.

1. Similar to the suction line the response is predominantly at 1X and a little lower at 3X. Other components are negligible and hence not shown in the Table above.
2. The change of mounting of compressor from flexible to rigid leads to lower levels of vibration.

Now in the absence of any standards the valleys of vibration levels have been used only for comparative purposes. The values also establish that the compressor is the predominant source of excitation of the tubing, in here again when it comes to design and when you do not have standards we did not know what level of a excitation is acceptable. We had to look at comparison and look at something which was not going to make a significant improvement from our status which was resulting in failures.

So, we used it more as a reference as a guide as to what would a design change do, you now choices before us were to continue using flexible absorbers which were expensive which were important from a company in the US or look at providing flexibility by design. So, we took the approach of the second which is make use of flexible copper tubing and reorient them so, that the natural frequency is away from both the track excitation frequency which is in the 0 to 20 Hertz range and the first and third harmonic of the compressor vibration the compressor excitation frequency.

So, which is around 50 Hertz so, we look at 48 Hertz more because there is a slip between the rotor and the frequency. So, typically 47 and a half 48 would be the first excitation frequency and 135 or thereabout would be the third excitation frequency and knowing that it is a 3 cylinder compressor and the data that we measure we look at these 2 and stay away from natural frequencies of any tubing which comes close there close to these numbers.

So, the results of measurement of the discharge line with the absorber are again given here in table 5 and I think rather than go by the specific 1 X, 2 X and 3 X we can look at the overall acceleration the RMS velocity in millimeters per second and that shows that with where the status which was in field a flexible number 4 flexible compressor mounting and in the horizontal direction we had 144 millimeters per second of velocity there was a significant iron cobalt or any other reading that we have.

And then we also can conclude here that change of compressor mounting leads to lower levels of a vibration. So, from flexible to rigid when you look at the horizontal acceleration it drops by almost one third 144 to 57.4. So, this built confidence that moving from flexible to rigid mounting of the compressor is going to cut down the displacement of the tube.

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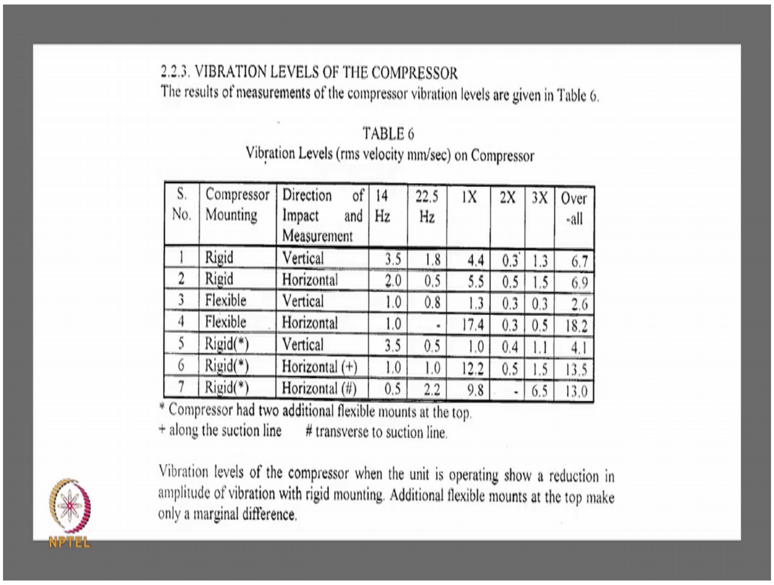

2.2.3. VIBRATION LEVELS OF THE COMPRESSOR

The results of measurements of the compressor vibration levels are given in Table 6.

TABLE 6

Vibration Levels (rms velocity mm/sec) on Compressor

S. No.	Compressor Mounting	Direction of Impact and Measurement	14 Hz	22.5 Hz	1X	2X	3X	Over-all
1	Rigid	Vertical	3.5	1.8	4.4	0.3	1.3	6.7
2	Rigid	Horizontal	2.0	0.5	5.5	0.5	1.5	6.9
3	Flexible	Vertical	1.0	0.8	1.3	0.3	0.3	2.6
4	Flexible	Horizontal	1.0	-	17.4	0.3	0.5	18.2
5	Rigid(*)	Vertical	3.5	0.5	1.0	0.4	1.1	4.1
6	Rigid(*)	Horizontal (+)	1.0	1.0	12.2	0.5	1.5	13.5
7	Rigid(*)	Horizontal (#)	0.5	2.2	9.8	-	6.5	13.0

* Compressor had two additional flexible mounts at the top.

+ along the suction line # transverse to suction line.

Vibration levels of the compressor when the unit is operating show a reduction in amplitude of vibration with rigid mounting. Additional flexible mounts at the top make only a marginal difference.

And then we again did similar measurements on the compressor. So, there are 7 readings here on the compressor with rigid flexible and then there are 3 readings where we put in a star indicating a rigid with an additional clamp on top. The compressor has a height and if shunting shop is the major cause of failure holding the compressor on top would also reduce the vibration level or the displacement level if we were to be very specific.

So, vibration levels of the compressor when the unit is operating show a reduction and amplitude of vibration with rigid mounting additional flexible mount at the top make only a marginal difference. So, there is no need for the complexity of holding it on top and then the sub assembly test details so, I mentioned to you we did a simulation on a sub assembly by lifting the unit and dropping it suddenly in our defense equipment. So, these are details of those tests.

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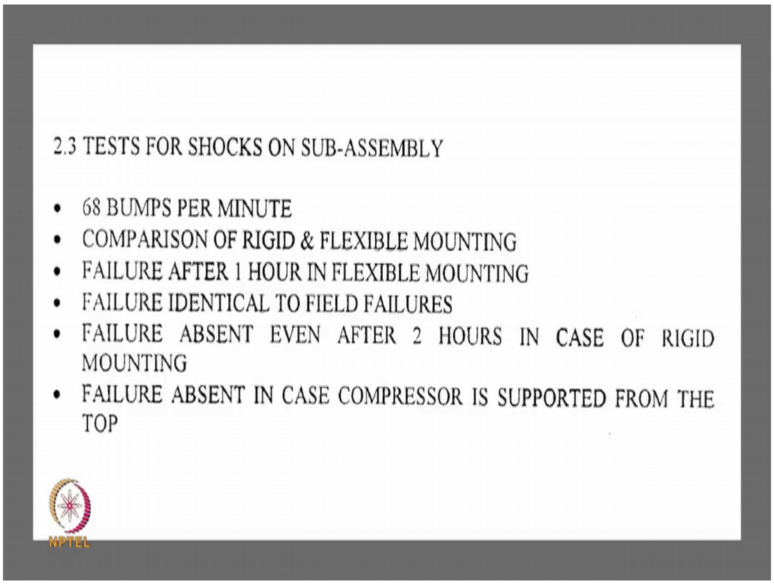

So, 68 bumps per minute and the comparison was made between rigid and flexible failure after one hour inflexible mounting and failure and integral to failed failures was the part that led us to confidence that flexible mounting was indeed. And we had railways come and witness this test so we could have their confidence that are analytical approach was leading to something which would have an impact on field.

So, the intention here was that this 6 month period that we had where we had no orders we had to get back the railway confidence get them to come and test the units again and have business flowing and that actually did happen. So, there was no failure when the compressor is supported I mean both the cases when it is having a rigid mounting and whether or not it is supported or did not make a difference. So, both cases the need for an additional mount on top was not there.

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CONCLUSION

Rigid mountings reduces amplitude of vibration in lines, increased the natural frequency, reduced relative motion between the compressor and lines.

TABLE 7

Natural Frequencies of the Connectors and Separation Margins from excitation frequencies for new connectors.

S. No.	Connector	Direction of impact and measurement	Natural frequency(Hz)	Separation margin from 1x	Separation margin from 3x
1	Left Suction	Transverse to loop	81	80%	40%
2	Left Suction	In plane of the loop	25,78	44%	73%,42%
3	Right Suction	Transverse to loop	86	91%	36%
4	Right Suction	In plane of the loop	68	51%	49%
5	Left Discharge	Vertical	31	31%	-
6	Left Discharge	Transverse	33	27%	-
7	Left Discharge	Axial	32	29%	-
8	Right Discharge	Vertical	31.25	30%	-
9	Right Discharge	Transverse	31.5	30%	-
10	Right Discharge	Axial	32.6	27%	-

So, now we look at conclusion, the rigid mounting reduces the amplitude of vibration increases the natural frequency and reduces the relative movement between compressor and lines and then we also redesigned connectors. So, I talked to you about flexible connectors without this pack less vibration absorber and with that we also had a separation margin which was clear and established from the natural frequencies and this is essentially showing the final design.

So, in the final design we had addressed vibrations, we had addressed reducing cost and we got back to the customer confidence and we had these units in operation however, the customer also became a little more alert to vibration. So, the facility in Bangalore was hired to do tests to the RDS spec. So, the unit would be put on a bed a very large bed which is typically used for aircraft tests and there you can excite the unit to different frequencies which can simulate both the track vibrations as well as the vibrations coming from other sources.

So, the 1 G the 3 G and the 0.5 G transverse was all done there and only there after that so, the units fed well in those tests. So, that was again confirmation that the work the analytical work that we did in terms of vibration analysis was effective.

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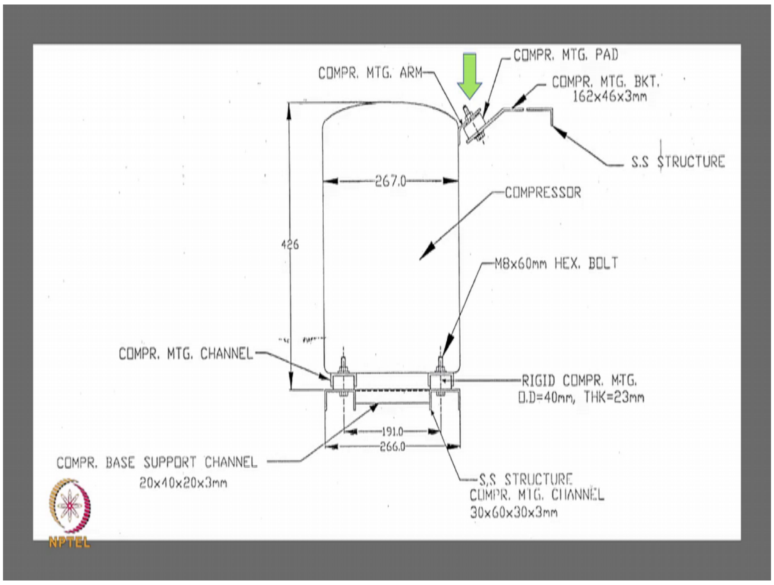

This slide is simply to show you the detail of a where we had put the additional clamp on top of the compressor. So, this is the place where it was put to evaluate whether it would further reduce the vibration levels or not and we did not find it worthwhile once they had rigid mounting at the bottom. This is just to give you an idea of what kind of channel was used at the bottom what height it is the detailing and the detailing becomes more and more critical as the application becomes demanding.

So, the rigid mount as there was a question right so, the rubber was replaced by a rigid mount which was 40 millimeters O.D and then there was a thickness of 23 millimeters that was to keep it raised above and we just kept the usual mounting locations of the compressor there were no change needed on the base of the channel that I used for modern compressors. So, with this we got back the business and these units continue to be in service in Rajdhani and Shatabdi are run today and there is a comprehensive RDSO spec that got evolved as we 100 several other things.

So, while we resolved the reliability issue there were some other things that were coming up. So, I talked to you about change in test conditions from 46 to 50. So, these trains would go at different stations they would be standing for a fairly long duration and you are aware of the shed which does not have a very significant separation between the top of the coach and the shade that is provided for passengers waiting. So, when these trains would stand there the compresses would trip and the compresses would trip and then they would reset their trip and then reset and then sometimes they would fail or sometimes are complaints or no cooling.

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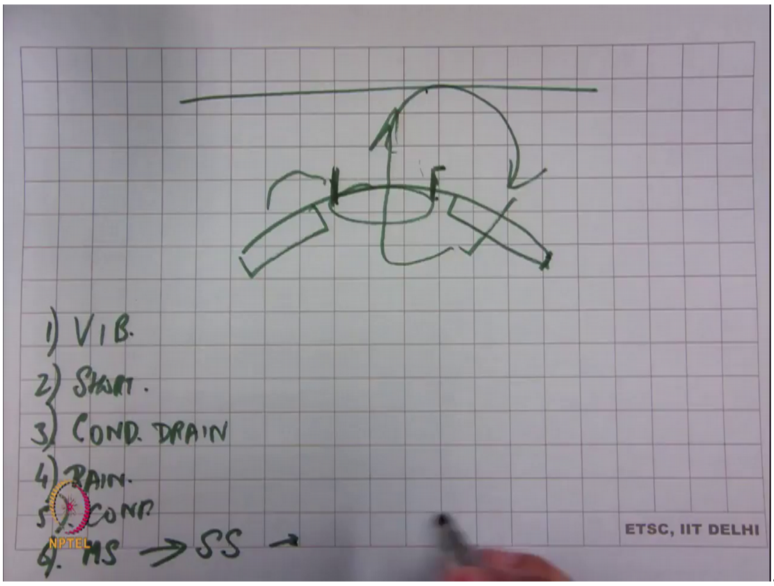

So, what was discovered was that when we have a coach we have air coming in and then there is hot air being discharged. So, long as it is free to air with no obstruction on top there is no problem the moment you provide a shed this air comes back in. So, there is short cycling and there is some robustness needed in the unit. So, there is a need to change the test. So, from 46 we suddenly were required to have the units deliver cooling at 50 degree centigrade. We also while doing all this discovered that irrespective of this cover or not there is also a certain amount of air that just comes back in because a natural flow of air.

So, we did some redesigning to provide a small duct of about 20 millimeters just ahead of the propeller fan that would direct the flow vertically upwards and then we had to go through the usual tests reoptimization and some of the tools available when you have space constraints are to increase the fin density to play with circuiting to optimize the circuiting better and all those were done, while you are doing all this the compressor manufacturer began to have issues in terms of reliability.

So, we address everything from our system design level and then we see the compressor is not really suitable for mobile applications. So, we increased the mean time between failures by making changes in the piping, addressing, vibrations, but whatever was internal to the compressor which was inherently a compressor designed for stationary applications begin to show up. And we could not get a single hermetically sealed compressor manufacturer to say on paper that their unit is suitable for railway application.

At the same time we have a demand where railways wants units something like 20 units a month to be supplied consistently. So, the Australian reference study that I had mentioned earlier proved handy there they had looked at scroll compressors and we looked at the internals of a scroll compressor there is no flexible mounting in a scroll compressor.

So, we got railways to agree on doing a trial and in the integral coach factory in Chennai they agreed to install the first unit with 2 scroll compressors. So, I still remember the model number of our compressors are 61 and while the market in India was still not using it even in stationary applications we had put it on top of a roof of a train and that decision proved to be a good decision because it led to a more reliable operation and then the spec slowly began to transition from reciprocating compressors to scroll compressors for railways.

In between this period of proving the design there were Danfoss compressor. So, manure Danfoss manure to compressors that were more robust. So, they were considered the workhorse in stationary applications and that was the best bet between the transition and till such time that you do have confidence on scroll compressors the user turner trains. So, they had spring mounts inside, but the string spring mounts were durable and they did not have clean it was a field trial that led to this observation that they would last longer and that was our second key. So, while application knowledge was helpful the whole thing went through a lot of field the learnings before this unit became acceptable in field.

So, I have talked to you about vibrations, talk to you about a short cycling affair, and just trying to remember is there something I missed then we talked about condensate drain ok. So, one other thing that came up was rain so, high speed movement of train and then there is rain. So, the condenser fan motors although they were rated IP 55 they were not withstanding the velocity that with which the water would hit the motors.

So, there was another learning phase where the motor manufacturers came in and we had to look at shower tests that would replicate this weakness in the motor at the test level. So, before the unit is shipped out of the factory can we detect that there is a motor and then when you do those tests you begin to realize that it is not just a question of degree of protection it is also a temperature variation that happens in the enclosure of the motor again something you do not learn in textbooks. So, when the motor is heated up there is a lot of hot air inside and then the compressor cycles.

So, the condenser fan motor and the compressor is switched off and it cools, in that cooling process it draws moisture with the air. So, when we are looking at protection from moisture we still are not preventing it from taking air. So, there had to be motor redesign such that that was not leading to accumulation of a water droplets inside the motor so, that to be a drain for that condensate to be coming out and enflaming. So, those are other learnings and these learnings who are leading to reliability improvements, but it was a painstaking process.

Because we were all finding out things that were not a message to at the design stage they were never document we did not know about it, but there was a good relationship between the manufacturers. So, the company I work for was not the only manufacturer, there was a competitors as well and then there was a fairly open forums and then there were problems which were there across the units it was not restricted to a particular unit and they were things later the service. So, this good cooperation between the customer, the service units of Indian railways and the manufacturers led to continuous improvement.

So, I talked about condenser motors then there was corrosion. So, the frame used to be made of MS. So, from mild steel to stainless steel along with the definition of a grade 3 0 4 was another change that happened and you make a change for RDS order simply one spec change they do not want to paint it they want access, but at the manufacturing level you certainly need to be prepared to weld thin sections to thick sections you have a frame and the entire welding apparatus needs to change the skill level of people need to change.

So, all that was another thing that was the learning and then what was all this done for you might ask right.

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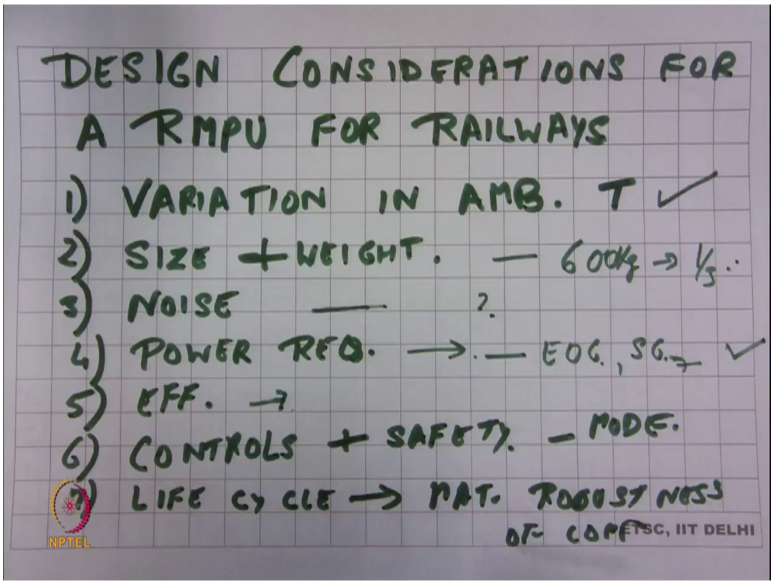

So, this first one across the country since we went to testing temperatures of 50 degree centigrade so, this was met, here this weight was in the region of a 600 Kgs it was almost one-third of the earlier unit. Noise in this particular application because the connection is through ducts canvas ducts between the unit and the passenger area there never was really an issue or people have not become sensitive enough whatever so, this really has not become a core issue right now.

So, I would just leave it as a question mark power requirement. So, this is something I missed between different manufacturers supplying the motors for condenser fan and also the transformer that was it was used for the control application, there was a need to revalidate things using temperature rise with the pulse width modulated power supply.

So, while the units worked fine for end on generation there was something called self generating coaches which required some changes, but finally, this was addressed. So, the robustness level of the motors and the control equipment was altered. So, that they do not overheat with the modified waveform ok. Now efficiency while it is a design consideration it did not show up as a major concern and the reason was what was being replaced was far more inefficient then the units that were being made available with the semi with the hermetic compressors.

So, the COP of systems with R 12 and semi hermetic compressors was far low I do not even remember measuring it or even a single in the specs. So, this is not show up, but today it might if you look at new technology today it could be you know a possible evolution that we can have. Controls and safety I am going to touch in a while, but this was addressed again lifecycle you have seen the number of things I have talked about and maybe I missed a few small ones. But then this was also addressed and the fact that now it has survived more than a decade no problem there.

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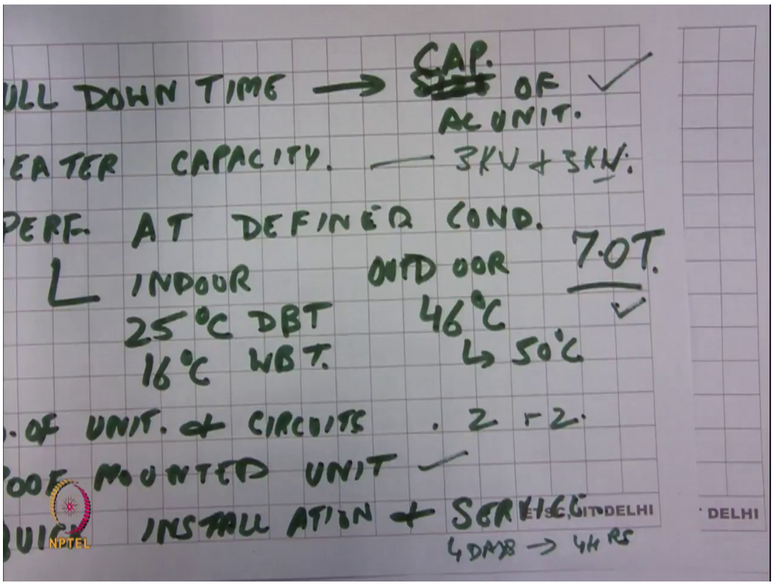

Pull down capacity we had never any issues on this heater capacity 3 kilowatt per side. So, 3 kilowatt plus 3 kilowatt was what was being used by railways earlier and based on field experience no one really has complained about it. So, this is not something investigated in great detail an opportunity here is can we use a heat pump. So, can we cycle the refrigeration circuit so, that we do not use heaters, but instead use a heat pump not much has been done on that and it is more to do with availability of power and size and all that this was a acceptance criteria.

So, this is addressed; this I talked about 2 units and 2 circuits, this was 4 days to 4 hours. So, now, are there any other requirements that we think you are not addressed? While I have been talking did you think of any other requirement, have you traveled and found something missing in an air conditioned coach? One thing I misses is that if every compartment like there are several sections you know 3 tier or 2 tier coach if every section could have its own control. So, that that continuous negotiation between different occupants about what is the right temperature is done away with.

Student: (Refer Time: 35:34).

Yes that is another so, now, I know that you are thinking. So, what all we can address by design.

Student: (Refer Time: 35:46).

Right.

Student: (Refer Time: 35:50).

Yeah.

Student: (Refer Time: 35:52).

So, the newer aircraft have an adjustable thing so, every occupant more or less can adjust the air director at (Refer Time: 36:04).

Student: (Refer Time: 36:05)

Yeah, but it is more like even in your car if there are 2 people one side you have sun, the other side not having sun. So, one easy way of adjusting is do you reduce the air flow see you, but something which could sense temperature for the occupant and allow him his own individual setting. So, some of the luxury cars today have it. So, the passenger the co-driver seat could have it is own temperature and the driver could have his own temperature, but these are again here.

So, this is good I mean when we think like this we are looking at unmet needs and that could be the evolution of design towards something else. So, we have not touched controls as yet right. So, how do we make sure that the compressor runs reliably? So, there was another part of this whole unit which was called a control panel.

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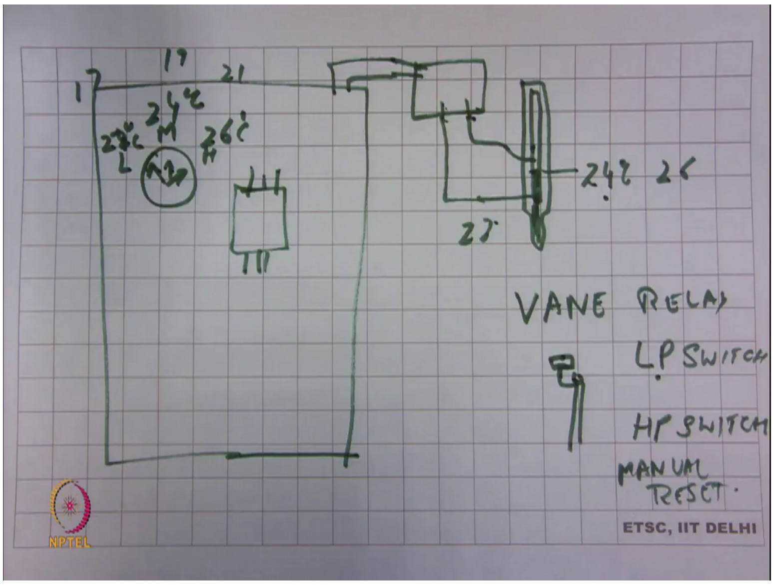

And this control panel had the user interface so, it would have a rotary switch which would define 3 levels of cooling low medium and high and this the sensing of it was done using mercury in glass thermometers so, it turns out right. Now, if you look at it in the in an area where there are a lot of sensors electronics and all that it seems very crude, but it turns out it is one of the very accurate means of sensing temperatures.

So, you have mercury inside a working last thermometer, but in addition to that when we are draw it again or let us say this is the mercury inside and we have it represent a certain temperature. So, let us say 24 degrees centigrade so, there is a metal conductor which is immersed in the mercury and the point of setting. So, this goes to something which is called a triggering circuit, which has some diodes and all that and I am right now not remembering the whole circuit, but what it does is that whenever there is contact between these two it powers the relay and that relay in turn energizes the compressor contactor.

So, this comes into the control panel and then somewhere there is a contactor which is a 3 phase contactor and that powers the compressor and the condenser fans. So, this becomes a way of controlling so, the medium setting is at 24, the high setting is 26 for comfort and then depending on the type of coach which is today's condition, it is either 24 on low or 22. So, in first AC they keep it at 22 degrees centigrade the time we were making these units irrespective whether it was for or second AC or a first AC it was 22, 24, 26 and again in for heating conditions it was 17, 19 and 21 these are the conditions which were maintained.

So, there were 3 set of thermostats there is one at 24 there is another one at 26 and then there is another one at 22. So, each of these would energize the pilot relay and the pilot relay depending on the rotary switch position would control the temperature at 22 or 24 or 26 and there was a need for some interlocks. So, you always want to have make sure that the compressor runs only if there is air circulation. So, to check that there is air flow there is something called a vane relay this is a simple flap with a microswitch connected to it and the microswitch gets energized when there is air flow.

So, when there is air flowing in lifts the flap and that is interlocked to the compressor contactor. So, the compressor will switch on only if the vane relay is on, so, this is another element of a control. Now you have the air flowing at the same time that is some problem with the circuiting and the or there is no refrigerant and you still want to protect the compressor. So, then what do you do so, then you have a low pressure switch and then you need to define what happens when the pressure goes low, do you want to reset it automatically or do you want to reset it manually.

So, for low pressure this switches an auto reset type, for any reason if the temperature has gone lower the pressure will go low and then the compressor is protected. Similarly you could also have conditions where the condenser coil is blocked on the condenser fans are not working anyone protection. So, you also have an HP switch so, the HP switch is a manual RESET type. So, once this trip then someone needs to attend to the unit before it can be switched on again.

And these are basically ways of ensuring a high uptime and addressing small issues like clogging of condenser coils and all that without much cost for railways. This is an evolution of the whole thing and right now there this has also been work to look at connected control panels. So, that at one place a person can know; what is the fault condition of different panels and that. So, we have talked about control panel then we always will have in an electrical device the usual protections for short circuit, overload and for that the combination used was overload relays as well as MCBs for each of the motors and then when you look at an application like railways different manufacturers will end up having their own layouts and component selections. So, there was a need for standardization.

So, there would be group meetings which would result in a layout that was acceptable to all so that in service people are used to a common interface. So, we had the same size of MCBs for the condenser fan motors, for the compressors, for the blower motors and all that and it was finally, put into a spec and maybe I can give you a glimpse of the spec.

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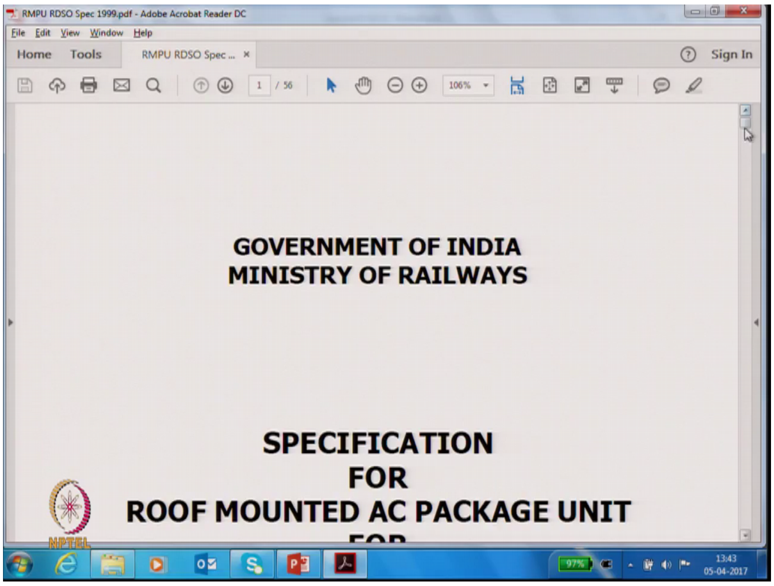

So, this is the final standard that was released by RDSO.

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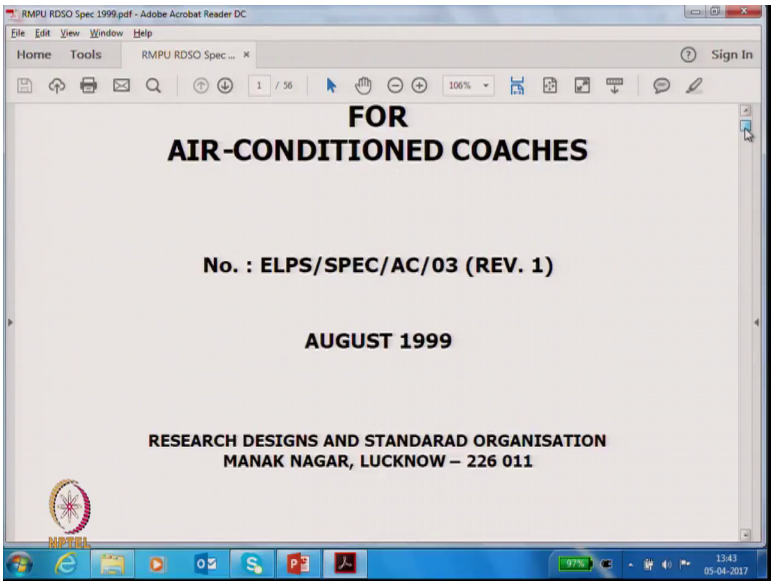

And this is available on the net so, any of you wanting to get into more detail for this can look at it.

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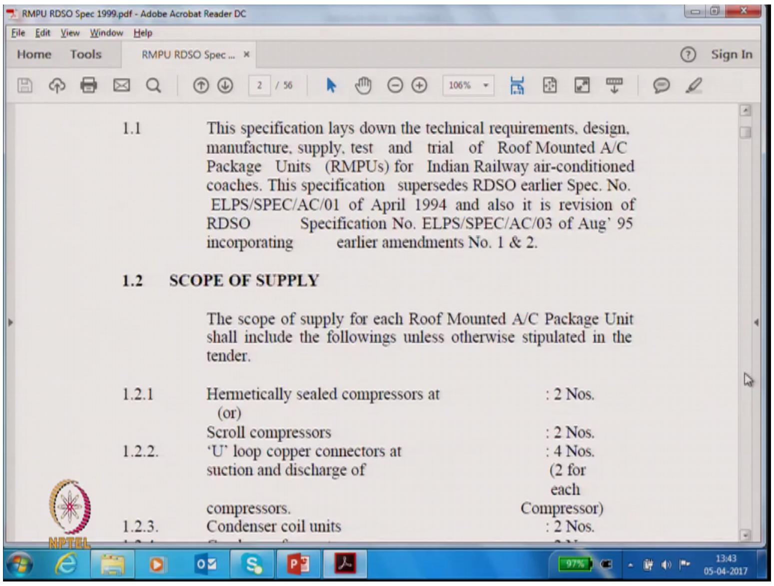

So, we will quickly scan this. So, there are 2 hermetically sealed compressors or scroll compressors.

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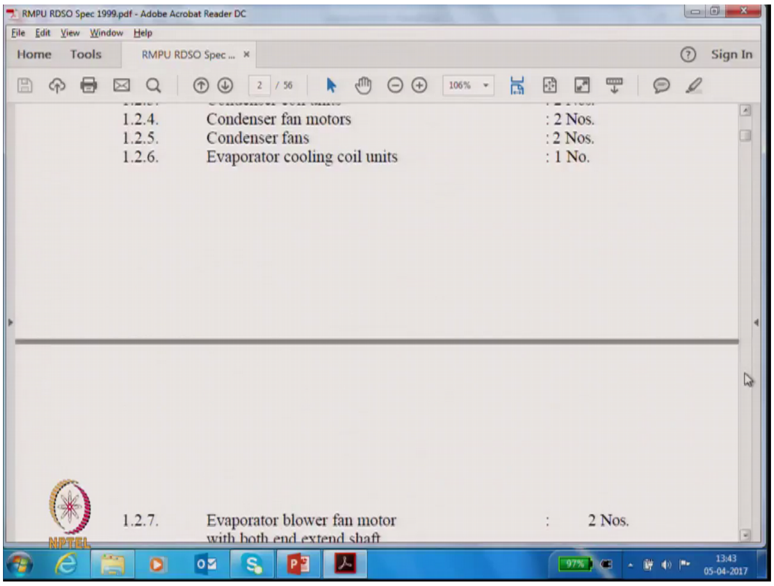

Then these condensers connectors have all come into the spec; now U loop copper connectors at suction and discharge of compressors.

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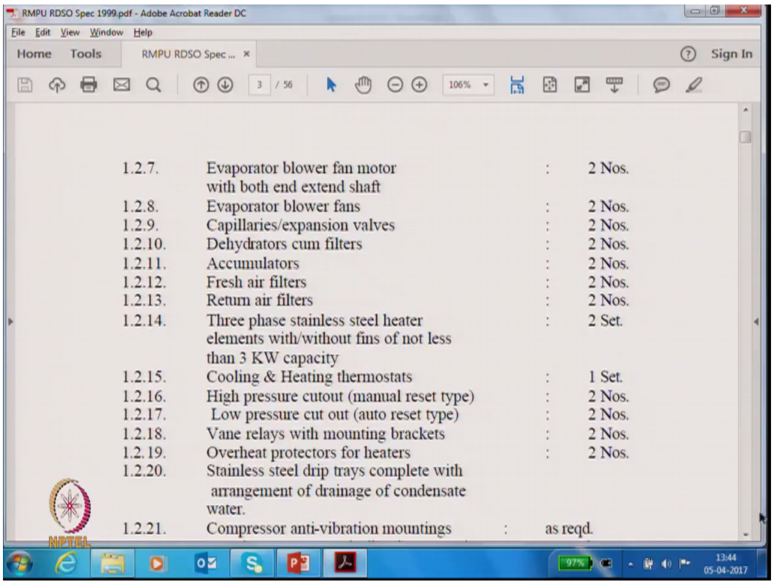

Rest are self explanatory then there are capillaries, accumulators, fresh air filters, filters one area we did not touch. So, there is an aspect developed for filters and then we are a proposal to put in a sensor for a dirty filter which did not get implemented that time and I do not know right now what is the current status, but there was an intent it was addressed through the LP switch setting auto reset type.

Then you can see all the components most of which we have discussed the condensate drain is referred to as drip tray.

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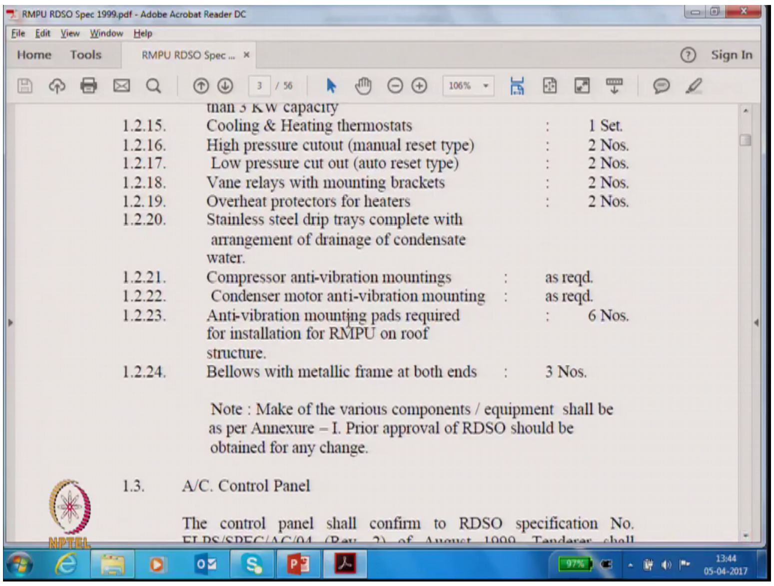

Then there are anti vibration mounting pads required for installation of the roof mounted package unit on the structure 6 numbers these address separation of a unit vibrations from the frame.

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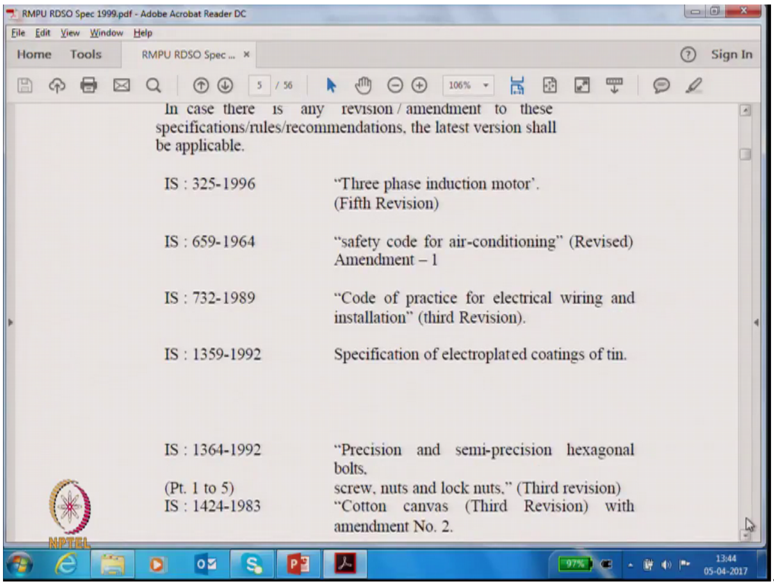

There are a whole lot of Indian standards that are referred to for different components that are used the whole intent being standardization.

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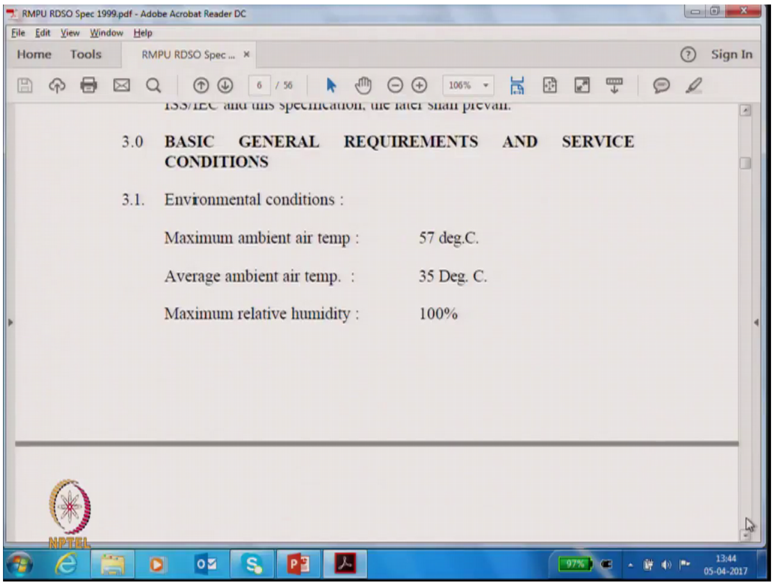

So, then to address the robustness part the max ambient temperature was also increased, so, from 55 it was increased to 57 and the unit had to operate for 2 hours without tripping at 57 outdoor air condition.

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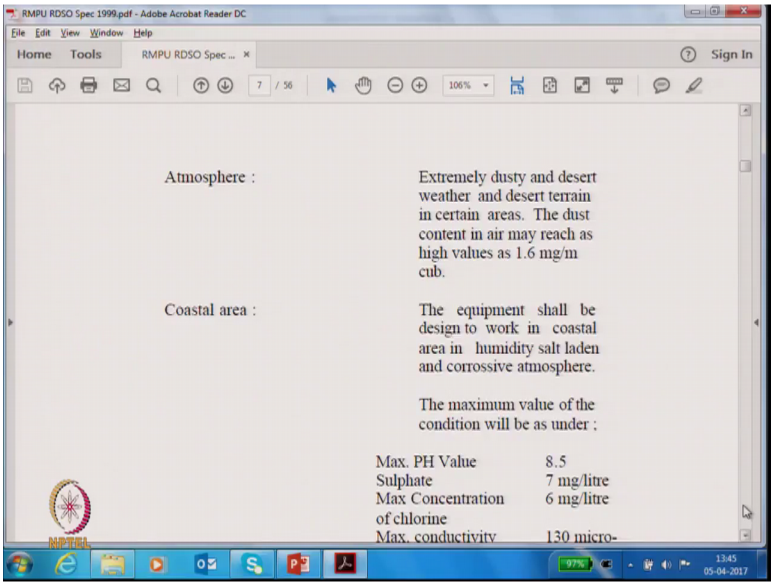

For addressing corrosion again we had some specs introduced and stainless steel actually ended up most of the corrosion problem, but as far as aluminum coils are concerned they were replaced by copper. So, the fins from aluminum which changed to copper and there was a anti corrosion coating of tin.

So, tin coated copper fins was one other robustness improvement element that was introduced in this product ok. Then to ensure the frequencies that are encountered on the coach or in the train and there was a test to take the frequency down to 47.5 and take it up to 52.5 and ensure that no vibrations will result in failures of components.

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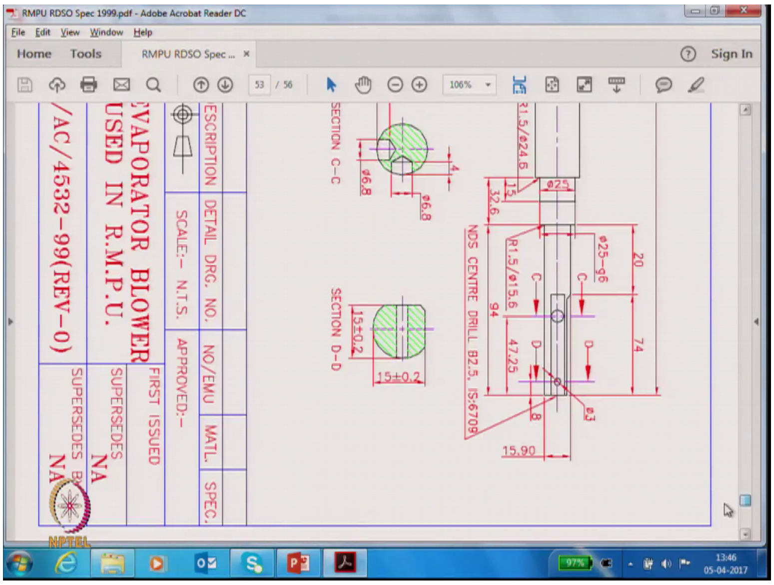

If you are interested you will be able to see the drawings of the unit, this is the triggering circuit that I mentioned where the signal from the thermostat the mercury glass thermostat is used to drive a relay; this is the detailed layout of the unit. So, if you want I will put in a link to this document that you can download from the website and with this I come to close.