

## Surface Finish and Deposits

The surface finish of the steam path has a major impact on the efficiency of a turbine stage, i.e., the efficiency with which the kinetic energy in the fast moving steam flow is converted to torque and power on the turbine shaft. In the case of deposits, they have two undesirable impacts on the stage performance. They reduce the available flow area, which reduces the flow passing capability of the turbine if they occur in the HP turbine, or they change the energy distribution, usually in an undesirable direction, if they occur in the IP or LP turbine. More significantly deposits significantly degrade the surface finish no matter where they occur. It is this latter characteristic of deposits that we will be dealing with in this presentation.

Figure 1 is a photograph taken by an Encotech audit specialist of a unit that had experienced significant deposits. The question, of course, is how much this has impacted turbine performance.

**Figure 1**



As you can see, the surface is not only roughened significantly, but the roughening is highly non-uniform. This latter presents a problem for evaluating the impact of the change in surface finish.

In the 1960's, the English Electric Co. undertook the task of trying to quantify the impact of steam path surface finish on turbine stage efficiency. They entrusted the task to the very competent head of their Aerodynamic laboratory, Mr. V. T. Forster, who subsequently published a technical paper describing the results of his investigations. To our knowledge this is the most comprehensive work carried out on this subject.

Encotech, Inc. has made extensive use of Mr. Forster's published information, plus benefiting from some additional insight gained through private correspondence with Mr. Forster following his retirement from English Electric Co.

You can quickly summarize Mr. Forster's results by saying that roughening up the surface of the steam path is very bad for stage efficiency and particularly so if it occurs toward the trailing edge of the stationary or rotating blades, where the steam velocities are highest. This, of course seems intuitive but the important result from Mr. Forster's work is that a means is provided for quantifying the impact of whatever roughening occurs and the importance of where it occurs.

Mr. Forster ran a number of laboratory tests with turbine cascades, where he had covered the blade surfaces with different grades of emery paper, and, as will be discussed later, Encotech, Inc. has made use of these same grades of emery paper to provide a means of judging the surface roughness in a turbine steam path that is being examined.

The steam path in a modern turbine should leave the factory with a surface finish that is the equivalent of 32  $\mu\text{in R}_a$ . Some of the things that can cause it to degrade (get rougher) than this value are;

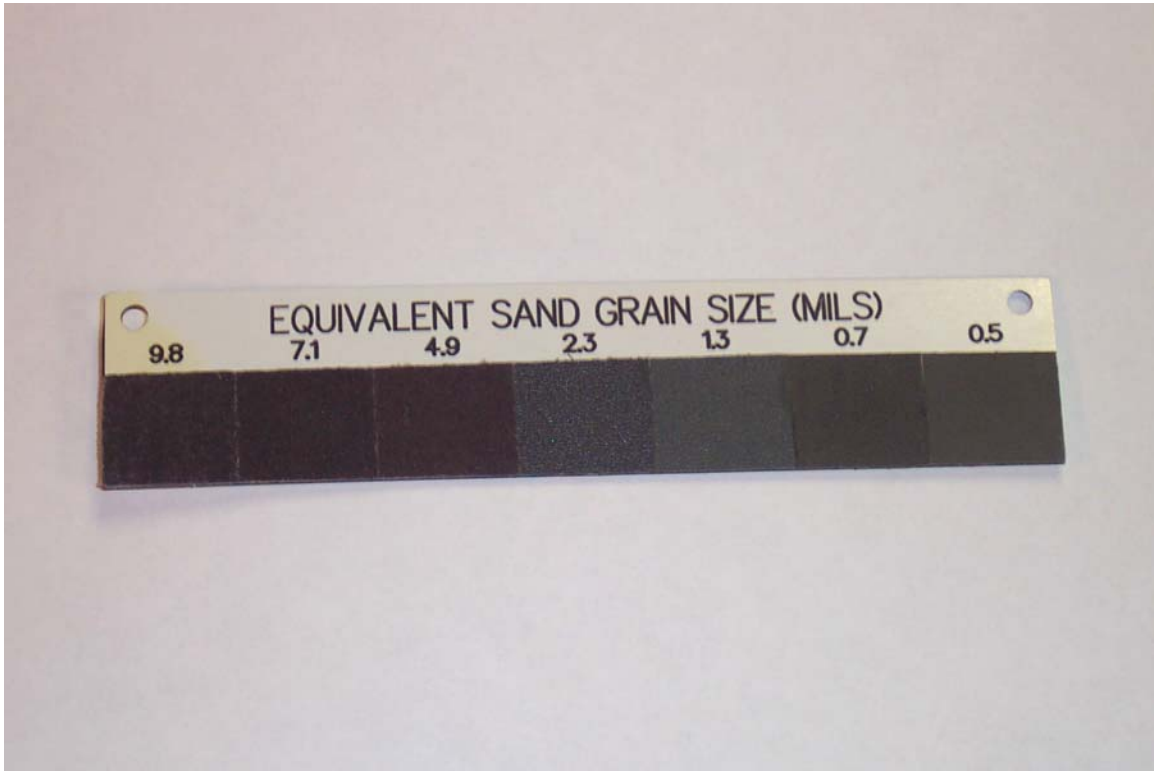
- 1) Deposits
- 2) Mechanical damage
- 3) Erosion
- 4) Grit blasting
- 5) Chemical attack

Encotech's eSTPE program addresses the evaluation problem in a multi-task approach. First of all, the program lets the user, for each stage, separately for each surface (pressure and suction side of blade), and separately for the stationary and rotating blades, define up to 4 different regions (averaged for all blades around the circumference), each having a user defined proportion of the total surface (the only constraint is that the sum of all regions must add up to 100%), and using the Encotech comparator, assign an equivalent sand grain size to each portion of the surface.

As shown in Figure 2, the Encotech comparator makes use of the grades of emery paper that Mr. Forster used in his laboratory tests, and identifies their "Equivalent Sand Grain Sizes". The user will compare the observed surface on the turbine blade with the

comparator, both tactilely, and by visually comparing the surface with the comparator using a magnifying glass. The best match will then be entered into the computer for the region being defined.

**Figure 2**



At this point the computer program takes over and:

- 1) Identifies, from data obtained from Mr. Forster's paper, the impact on stage efficiency if the entire blade were covered uniformly with the deposit
- 2) Determines, again using results from Mr. Forster's lab tests, the significance of the portion of the blade that is actually affected with the entered sand grain size.
- 3) Performs the process described in 1) and 2) for all sections of suction and pressure sides of the rotating and stationary blades.
- 4) Determines the Reynolds No. for the stage being analyzed. This is important because the Reynolds Nos. change from the inlet to the exhaust and this affects the significance of a specific degradation in surface finish.
- 5) Reports the loss in output and the increase in heat rate that results from the degraded surface finish for each turbine stage that is affected.

A typical eSTPE output report will look like Table 1.

**Table 1**

**Audit Results: Opening Mar, 2004: Surface Roughness: HP Casing**

<b>Description</b>	<b>Stage Efficiency Loss</b>	<b>Power Loss</b>	<b>Change in G.T.H.R.</b>	<b>First Year Fuel Cost</b>
	<b>%</b>	<b>kW</b>	<b>Btu/kWh</b>	<b>\$</b>
Stage 1	1.58	244.2	1.53	12,858
Stage 2	1.88	285.1	1.79	15,044
Stage 3	4.34	680.0	4.27	35,886
Stage 4	4.34	700.7	4.4	36,979
Stage 5	4.96	829.0	5.2	43,702
Stage 6	3.47	599.5	3.76	31,600
Stage 7	3.29	588.5	3.69	31,012
Stage 8	3.25	604.9	3.79	31,852
Stage 9	3.48	671.2	4.21	35,382
Stage 10	3.25	652.3	4.09	34,373
Stage 11	3.01	632.1	3.96	33,281
Stage 12	2.14	472.4	2.96	24,876
Total		6,960.1	44.02	369,953

It is interesting to look at the distribution of losses through the turbines stages for a given change in surface finish. For this example the unit selected was a 580 MW unit, 3500/1000/1000 inlet conditions, opposed flow HP-IP turbines in a single outer casing, four-flow low pressure turbine. The assumption was made that the surface finish was roughened to an equivalent sand grain size of 2.3 mils., over all the blade surfaces.

Figure 3 shows the impact on stage efficiency and Figure 4 shows the resulting loss in power output for each turbine stage. Note that the stage efficiency losses were averaged for the four LP turbine flows and the power losses were summarized.

Figure 3

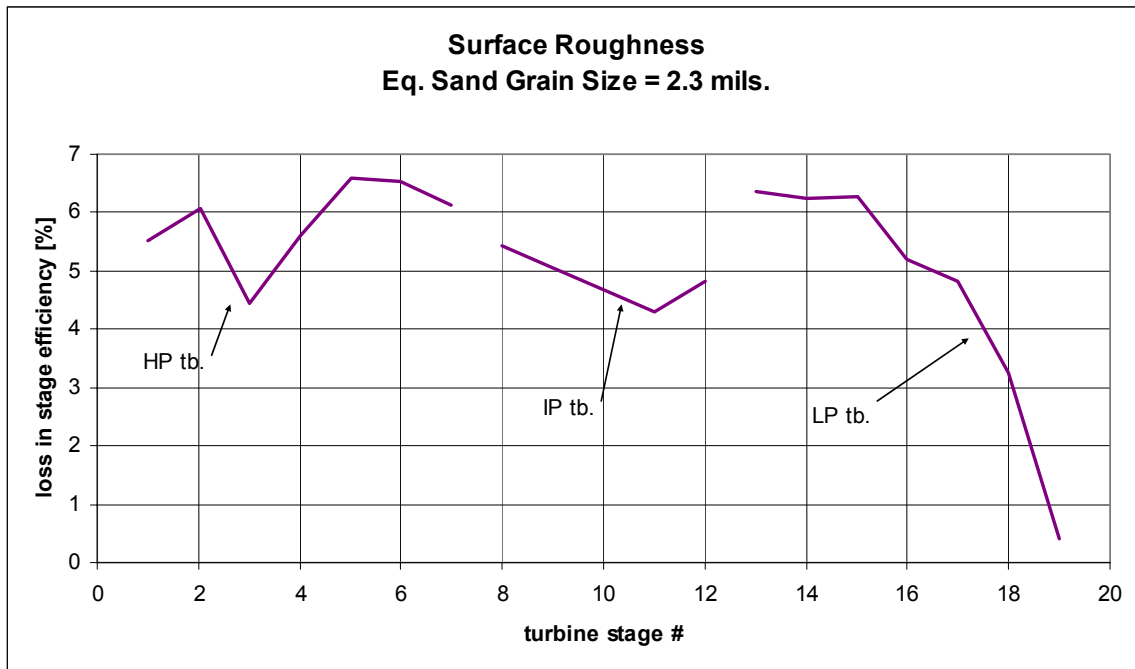
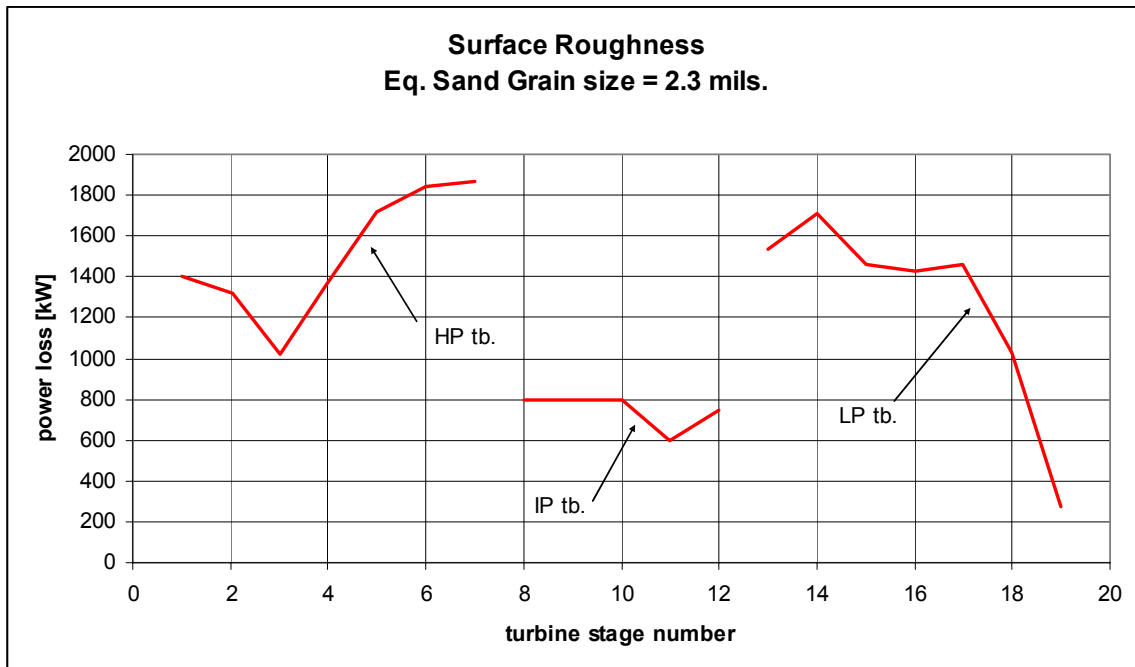


Figure 4



The most significant observation is that the power losses vary considerably from one stage to the next, even though the roughening of the surface was assumed to be the same for all stages. There are a number of additional observations of interest, but before

discussing them, let's consider the things that might make the losses differ from one stage to the next.

Losses due to increased roughness are basically a boundary layer phenomena, where the main stream flow, at some velocity, is trying to slide past the stationary boundaries of the flow path. The resulting shear stress in the fluid in the boundary region produces a conversion of kinetic to thermal energy and the rougher the surface, the greater the amount of the flow that is involved in this high shear stress region. Two conclusions that result from this observation, and that are consistent with the laboratory test data, are that both increased roughness and increased main stream velocity, increases losses.

There are additional factors at work that impact the net turbine stage loss, however. Some of them are:

- 1) The available energy on the stage – stage available energies do vary throughout the turbine and a given change in stage efficiency will have a greater power loss impact on a stage with high available energy than on one with a lower value.
- 2) The stage reaction – a low reaction stage converts most of the stage available energy to velocity in the stationary blading, whereas one with 50% reaction distributes this conversion equally over the stationary and rotating blades. The former situation results in higher peak stage velocities, and therefore a given surface finish degradation will result in a greater loss on a low reaction stage.
- 3) The amount of flow through the stage – as the steam passes downstream through the turbine; some is extracted for feedwater heating. Thus the flow per stage diminishes as you progress from inlet to exhaust.
- 4) Loss recovery capability – a loss on any given stage results in an increase in the temperature of the steam flowing to the next stage, or out an exhaust, as the case may be. If there is a following stage, the energy available to that stage goes up a little and some of the loss is recovered. The more stages downstream of a stage suffering a loss, the more the recovery of that loss will be.

In the HP turbine there are only the stages between the stage suffering the loss and the HP turbine exhaust, because that exhaust passes to the reheater where there is a slight reduction in heat added in the boiler, but no power loss recovery. In the IP turbine there is a maximum number of stages between the one experiencing the loss and the final exit from the turbine to the condenser, so the possible loss recovery is much greater.

- 5) There is a Reynolds Number dependence of the impact on stage efficiency – the Reynolds Number decreases as the flow moves through the turbine and the loss imposed by a given roughening of the steam path surface also decreases.

The noticeable reduction in stage loss in the IP turbine as compared to the HP (Fig. 4) is due to a combination of factors: the stage efficiency loss has decreased somewhat (Fig.3), the flow per stage is less, and the loss recovery capability is much higher. The LP turbine power loss is back up because of a higher stage efficiency loss and higher available energy per stage. These latter influences begin to be overcome as the flow

moves downstream and the lower Reynolds Numbers in the latter stages reduce the impact of a given change in surface finish.

It should be noted that these are results for one specific design of turbine. While the general trends noted here will likely be present for other units, the individual stage magnitudes will likely vary considerably.

The important conclusion is that identifying the impact of a given change in surface finish can be done but it requires a computer program with a sophisticated analytical capability similar to the Encotech, Inc. eSTPE program.