The Steam Turbine Performance Evaluation (STPE)[(c)] Software Family

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Abstract

The Steam Turbine Performance Evaluation (STPE)(c) program evolved from an Encotech research project for Southern California Edison to computerize K. C. Cotton's methodology for conducting steam path audits. The purpose was to develop a software package to guide young plant engineers in determining what is wrong in a turbine steam path and what is worth fixing. The original fossil plant version of the program has been used for several years by a growing number of electric utilities and by Encotech on behalf of utilities to conduct turbine steam path audits. Stage-by-stage loss categories include packings and seal wear, solid particle erosion, surface finish and deposits, mechanical damage, and miscellaneous leakages.

An STPE(c) Nuclear version was released in December 1991. Industrial and Geothermal versions are in preparation. A Steam Turbine Redesign Evaluation (STRE)(c) program to calculate stage efficiencies and generator output and inlet flow at various throttle points has recently been introduced to permit evaluations of used turbines and turbine modifications.

The members of the STPE(c) software family are introduced, and their evolution and function is discussed in general terms.

The speaker is John M. Daniels, Encotech's Marketing Director.

The Steam Turbine Performance Evaluation (STPE)(c) Software Family

Introduction

In 1985 Southern California Edison began hiring consultants to conduct a series of efficiency appraisals of their generating units. Kenneth C. Cotton working with Encotech was one of three experts engaged for this work. The benefits of identifying the source of losses in turbines open for inspection and correcting the loss conditions before the units went back into services soon became apparent in guiding Edison's restoration of their turbines to near design efficiency. Edison then asked Encotech about the possibility of developing a software package to capture Mr. Cotton's steam path appraisal methodology as a tool to make it possible for plant performance engineers to do their own steam path assessments on a routine basis without need to hire a consultant. A joint research effort toward this objective was begun in 1986. The results have been highly successful. Edison estimates fuel savings of $5 million to $6 million annually have been achieved by using the STPE(c) program to identify steam path deficiencies and to prioritize the cost effectiveness of making repairs.

The STPE program has been made available to other utilities since 1989 under a royalty arrangement with Encotech that reimburses Edison for its project development costs. To date a total of eleven utilities have become licensed STPE users, and others have engaged Encotech to come on site to perform STPE-based steam path audits on their behalf. An "audit-by-FAX" service is also available to permit a plant to take its own steam path data and forward it to Encotech for rapid STPE analysis within the real time decision making limits of the outage. Audits are often performed prior to closing units to critique the condition of steam paths after their repair and refurbishment.

STPE Program Function

The main menu of STPE is shown in Figure 1. At this point one can either select a case if one has already been entered or enter into Design Definition to produce a stage-by-stage definition of the turbine to be evaluated.

Design Definition requires user input of information from the turbine manufacturer's design heat balance, turbine cross section, and steam seal and clearance diagrams to characterize each unit being evaluated in its "new and clean" condition. The program produces stage-by-stage turbine characterizations in the absence of proprietary OEM data. The program calculates a set of default values for the necessary design parameters such as blade heights, root diameters, sealing diameters, etc. Default values are replaced with measured values if differences are found when the unit is opened.

The other program sections are:
- o Operating Data - to evaluate the overall condition of a machine from data taken while it is in service.
- o Turbine Audit - to make an engineering evaluation of the power and heat rate loss of a unit from measurements made when it is open for inspection.
- o Performance Comparison - to determine the degree to which an audit has identified observed performance losses.
- o Economic Evaluation - to convert the engineering description of turbine losses to financial terms and so to permit an economic evaluation of the benefit of making repairs.
- o Reports - to generate summary report screens of the results of Operating Data Analyses, Turbine Audits, and Economic Evaluations.

Figure 2 shows the menu for the Turbine Audit section. Beginning as soon as the upper inner shells are removed, the audit engineer takes "as found" measurements of steam path condition. Areas of concern include:
- o leakages (mostly through damaged seals & joints),
- o surface finish (degradation from deposits, corrosion, solid particle erosion, mechanical damage),
- o flow blockages (from deposits and foreign objects),
- o increase in flow area (from solid particle erosion).

Depending on a unit's size and its rate of disassembly, data is taken over a period of several days. A detailed User Manual and program HELP screens describe the input requirements and explain the logic of the evaluation. The program calculates stage-by-stage losses by loss category and predicts the economic benefit of making repairs.

Table 1, which is taken from an example in the STPE User Manual, shows predicted first year fuel savings of making the repairs in each of the loss categories. Note that the calculation shows that not all losses from new and clean condition are to be recovered because in the example case it is assumed that the blades will be refurbished, not replaced.

Table 2, also from the User Manual, is a worksheet that allows the program user to optimize economic repair decisions. Entries are made for estimated repair costs and expected regain by making repairs. Sensitivity studies can be made for different costs, regain, and timing. This worksheet applies to the turbine as a whole. Other worksheets are available to permit similar analysis on the basis of individual turbine casings.

Table 3, which is from an article in the Southern California Edison Research Newsletter[1], shows how they have used STPE engineering output together with their own stage-by-stage repair costs to compare the benefits and costs of one particular approach to repairing or replacing HP turbine blading. In general SCE finds that fuel cost savings are at least twice the cost of repairs.

The Operating Data Analysis section of the program accepts performance data taken on an operating machine and makes conversions to the standard conditions specified by the Design Definition Section. There is provision for graphical presentation of trends of multiple tests. A Comparison section enables standardized comparisons between the results of a steam path audit and operating test data. Losses predicted by STPE-based opening audits can be compared with pre-outage turbine test results. Similarly, closing audit findings can be compared with the results of post-outage tests. It is gratifying that in discussing reconciliation of results at a recent STPE program presentation, a member of the audience from a company that is an STPE licensee volunteered that program results are now generally accepted as the standard when questioning the validity of test data. Those of you familiar with the trials of software development may suspect that this has not always been the case. Program accuracy is a tribute to the members of the Encotech staff who have developed the physics behind Ken Cotton's methodology and rules of thumb, encoded it into the STPE software, and patiently sorted out the bugs and inconsistencies.

STPE Nuclear

A special nuclear version of STPE was released in December 1991, and to date has been shipped to two utility users. The basic changes in concept from the original fossil plant version are:

1) the nuclear version limitation of steam flow from the reactor based on licensing restrictions (whereas the fossil version assumes that boiler flow will increase to the extent that the unit has the capacity to accept it),
2) that improvements in nuclear plant performance will increase the amount of power available for sale (whereas fossil plants will benefit from lower fuel consumption),
3) evaluation of moisture separator-reheater performance in the operating data analysis of nuclear plants.

[1] "Steam Turbine Performance Evaluation - Method Saves Millions," by Sam Gibson, Steam Division Engineer, and John McKinley, Senior Research Engineer, Research Newsletter, Vol. 20, No. 2, page 5, 3rd Quarter 1991.

STPE Geothermal

A geothermal version is being prepared. Differences from the fossil plant version include:
1) provision to account for field degradation,
2) ability to handle steam path moisture removal,
3) analysis in terms of steam rate rather than heat rate.

STPE Industrial

An industrial version of STPE is also in preparation. Differences from the fossil plant version include the ability to handle:
1) controlled extractions to process and steam admission,
2) heat rate calculations based on fuel chargeable to power,
3) variable speed machines.

Steam Turbine Redesign Evaluation (STRE)[c]

Some of the techniques used in the Design Definition section of STPE have been adapted to a smaller program to calculate stage efficiencies and generator output and inlet flow at various throttle points. The principles have been tested in service to a client to adapt surplus marine propulsion turbines to geothermal power generation. The program is expected to find wide use in evaluating used turbines and turbine modifications.

Conclusion

Each in their own way the STPE software family members are all grounded in the engineering principles of turbine steam path design. This paper attempts to give an overview of their intended function. Interested parties are invited to request an Example Report of an STPE-Based Steam Path Audit. Encotech's engineering staff will be pleased to discuss applying STPE software to meet special needs. Many thanks to our host, Halliburton NUS Environmental Corporation, for the invitation to make this presentation and to you, the audience for your attention.

Figure 1

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Encotech STPE....................................................MAIN MENU
UNIT...2 EXAMPLE
CASE...NOT ENTERED


                        1  Select Case
                        2  Design Definition
                        *  Operating Data
                        *  Turbine Audit
                        *  Performance Comparison
                        *  Economic Evaulation
                        *  Reports
                        8  Exit Program

                           Enter Number > 1


        NOTE: Un-numbered options become available after you select a case.
              Make sure DESIGN DEFINITION is finished before going to
              another branch.
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Figure 2

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Encotech STPE...............................................TURBINE AUDIT
UNIT...2 EXAMPLE                                                MAIN MENU
CASE...7
           ┌─Leakages
           │        ├──A--Interstage Packings      Use the UP and DOWN ARROW
           │        ├──B--End Packings             keys (or the preceding
           │        ├──C--Radial Spill Strips      letter) to select the audit
           │        └──D--Miscellaneous Leakages   you wish to perform. Press F1
           ├─Flowpath Damages                      to perform the selected audit.
           │        ├──E--Solid Particle Erosion   The RESULTS option MUST be
 Audit ────┤        ├──F--Mechanical Damage        selected AFTER all FLOWPATH
           │        ├──G--Deposits                 DAMAGES have been entered.
           │        └──H--Results
           ├─Miscellaneous Losses
           │        ├──I--Surface Roughness
           │        ├──J--Cover Deposits
           │        ├──K--Trailing Edge Thickness
           │        └──L--Other (Hand Calculations)
           └─Reports
                    ├──M--Summary
                    └──N--Clearance Graphs
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Table 1

Encotech STPE..ECONOMIC EVALUATION
UNIT... 2 EXAMPLE — TURBINE FUEL COST PREVIEW
CASE... 1

POTENTIAL FUEL SAVINGS - FIRST FULL YEAR ($ THOUS)

	<-----$ LOSS------->			UNREPAIRED LOSS
	NO REPAIR	REPAIRED	SAVINGS	BTU/KWH
INTERSTAGE PACKINGS	2.59	.00	2.59	16.61
END PACKINGS	4.60	.00	4.60	29.55
RADIAL SPILL STRIPS	2.43	.00	2.43	15.78
MISCELLANEOUS LEAKAGES	2.43	.24	2.19	15.56
FLOWPATH DAMAGE	.00	.00	.00	.00
SURFACE ROUGHNESS	13.71	1.37	12.34	88.88
COVER DEPOSITS	.11	.01	.10	.70
TRAILNG EDGE THCKNESS	.27	.13	.13	1.70
OTHER (HAND CALCS)	.00	.00	.00	.00
TOTAL	26.14	1.76	24.38	170.79

AUDIT LOSS (KW)........... 16459.20 — CAPACITY FACTOR (%)...... 65.00
FUEL COST ($/MBTU)........ 2.80 — BOILER EFFICIENCY (%).... 85.00

Table 2

Encotech STPE..ECONOMIC EVALUATION
UNIT... 2 EXAMPLE — TURBINE WORKSHEET ($ THOUS)
CASE... 1

	REPAIR COST	REGAIN (%)	UNREPAIRED LOSS ($/Y)	PLANNING PERIOD SAVINGS CUMULATIVE	PRES WORTH
INTERSTAGE PACKINGS	10.	100.	2.39	3.82	2.26
END PACKINGS	20.	100.	4.25	4.59	1.80
SPILL STRIPS	10.	100.	2.24	2.98	1.51
MISCELLANEOUS LEAKAGES	6.	50.	2.24	.48	-.25
FLOWPATH DAMAGE	0.	0.	.00	.00	.00
SURFACE ROUGHNESS	30.	50.	12.66	6.62	2.47
COVER DEPOSITS	0.	0.	.10	.00	.00
TRAILING EDGE THCKNESS	0.	0.	.25	.00	.00
OTHER (HAND CALCS)	0.	0.	.00	.00	.00
REPL GENERATION	5.38			-5.38	-5.38
TOTAL	81.38		24.13	13.12	2.40

TIME UNTIL REPAIRS (YRS)... 0 — REPAIR OUTAGE (WKS).... 4.
PLANNING PERIOD (YRS)....... 5 — FUEL COST ($/MBTU)..... 2.8

FOR SENSITIVITY STUDY...CHANGE COST, REGAIN, OR TIMING...THEN PRESS F1.
FINAL DECISIONS FOR REPAIR AND REGAIN WILL BE ENTERED ON THE NEXT SCREENS.

Table 3

Economic Evaluation for HP Blading

HP Turbine	Cost $	Audit Benefit Btu/kWh	Econ. Life Ben. Btu/kWh	Ben./Cost Ratio
HP Stage ·				
7	$28,462	4.52	4.24	1.15
6	$14,967	6.16	5.78	2.98
5	$17,725	8.41	7.90	3.44
4	$16,110	6.56	6.17	2.95
3	$22,973	9.18	8.63	2.90
2	$23,901	11.68	10.97	3.54
1	$38,648	16.43	15.43	3.08
HP Summary	$162,786	62.94	59.12	2.80