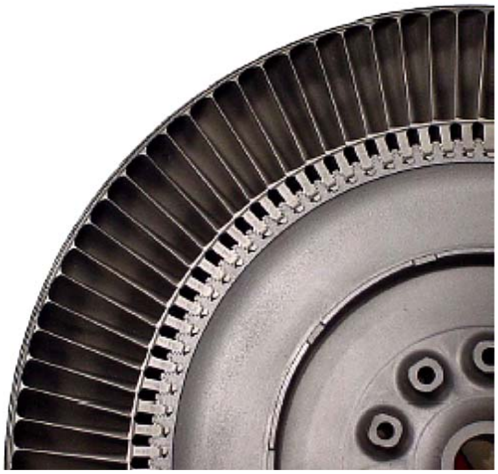
AN EVALUATION OF FOUR BLADE PLACEMENT OPTIMIZATION PROGRAMS



In gas turbine and jet engine applications using non-integral compressor blades and turbine buckets, the weight tolerance of the individual blades or buckets can significantly affect the balance of the assembled rotor.

Even though the weight differential may be very small, if random assembly places more of the heavier blades on one side of the rotor, the resulting imbalance condition may be more than can be corrected by additional balance weights or machining processes. This may mean disassembly of the rotor and time-consuming repositioning of the blades to attempt to achieve better balance. Given the millions of possible blade combinations for even small rotors, repositioning by guesswork is virtually impossible and computerized numerical methods are usually employed. This article discusses four types of blade placement optimization programs.

Fixed Opposition Methods

The most common software solution for determining optimum blade placement is the simple Fixed Opposition Scheme. This method determines the rank of each blade's weight and places blades of adjacent ranks in opposition or in a pattern of position to attempt to achieve balance. There are a number of variations of this method but none of these schemes can provide anything like optimum balancing nor can they factor in initial wheel imbalance, if available, or work with special blade types – blades that must be installed in one particular slot to achieve a particular design function. They are entirely repeatable, however, and are easy to understand with results that are easy to visualize. Since they are basically worked out by hand, a computer is not needed, making them convenient for field repair.

In an example of a simple 12 blade rotor, a typical Fixed Opposition lay-out installs the heaviest blade in the Slot 1 position. The second heaviest blade is put into Slot 7 (directly opposite Slot 1 in the 180 degree position). The third heaviest blade is placed in Slot 4 (the 90 degree position) and the fourth heaviest blade is put into Slot 10 (the 270-degree position. The next four weight-ranked blades repeat the pattern with the Slot Number incremented by one, e.g. The fifth heaviest blade is placed in Slot 2, the sixth heaviest in Slot 8, seventh heaviest in Slot 5 eight heaviest in Slot 11. This pattern is repeated until the rotor is completely populated.

This type of arrangement is called a "4-pole" or "90 Degree" pattern. Other Fixed Opposition programs use a 2-pole (180) degree or 3-pole (120 degree) placements. Some use more than one type and select the pattern that yields the lowest unbalance. Obviously these types of programs run into difficulty with an odd number of blades or a number that is not divisible by the number of poles. In these cases the remainder of the blades are used to fill in the remaining slots as best they can.

Heuristic Methods

Heuristic Methods have become more common as computing speed has increased. These methods work very differently than the Fix Opposition methods, usually starting by calculating the unbalance for a randomized placement of the blades on the rotor, then exchanging blades to create another pattern. If the unbalance of the second pattern is smaller than the first, the result is recorded. If not, it is ignored and another pattern tested.

Conceivably, every possible blade combination could be tested in this way, given enough time. With our example 12 blade set there are only 479,000,000 possible combinations; this number of possibilities could be checked in a reasonable amount of time with a modern computer. A 30 blade set, however, has 2.65 x 10^32 possible combinations and would take considerable time to calculate. And a fairly common 75-blade set would take years of calculating time. The trick with a Heuristic method then is to find a way to direct the algorithm to achieve the best possible results in the shortest possible amount of time.

Even rudimentary Heuristics generally provide results superior to Fixed Opposition methods. They also have the advantage of being able to consider the initial unbalance of the rotor and, if properly designed, special blade types. Some Heuristics use a Fixed Opposition first stage to provide a starting place for calculation.

Four Programs

The results provided by four typical blade placement optimization programs are discussed in the following:

Program A is a simple 4-pole Fixed Opposition type.
Program B is a commercial program offered for sale by a specialist balancing company.
Program C is a GW Basic DOS program available as freeware
BALANCEPOINT is Turbine Metrology’s BalancePoint 5.0, a Heuristic method.

Graphics are included with the examples to aid in visualizing the blade distribution. In the case of Program A, and Program B, these graphics were obtained by populating a spreadsheet with the results. The BalancePoint graphic is taken directly from the BalancePoint Plot page, a standard feature of the program. For Program A, Program B, and BalancePoint, the graph is in polar form. These are presented uniformly with Slot 1 in the East (3 o’clock) position. Program C does not provide a polar plot but does provide a histogram.

Each program was run with two sets of real blade data. The data used in Example 1 was a 24 blade set from a General Electric 7FA first stage compressor with weights of about 7000 grams/blade and a weight variation of about 2.8%. The data used in Example 2 was from a Rolls-Royce Trent 500 first stage HP compressor with weights of about 35 grams/blade and a variation of 4.8%. These examples are representative of the range blade weights commonly seen in turbine applications.

EXAMPLE 1 – 24 blades (GE 7FA First Stage Compressor)

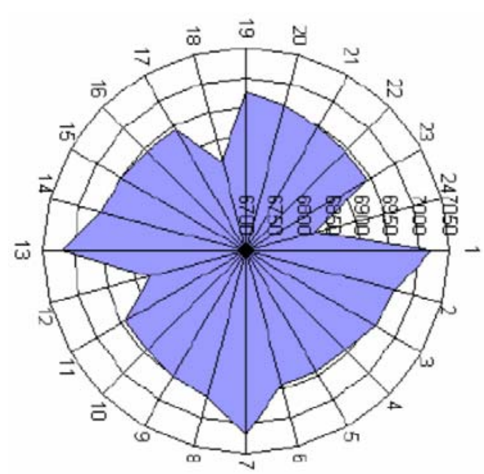
PROGRAM A

Results

Resulting unbalance: 2.9 gms
Unbalance angle: 59.3 degrees

Unbalance is ~ .04% of the nominal blade weight.
The 4-pole nature of the data is
obvious in the graphic.

Distribution graphic



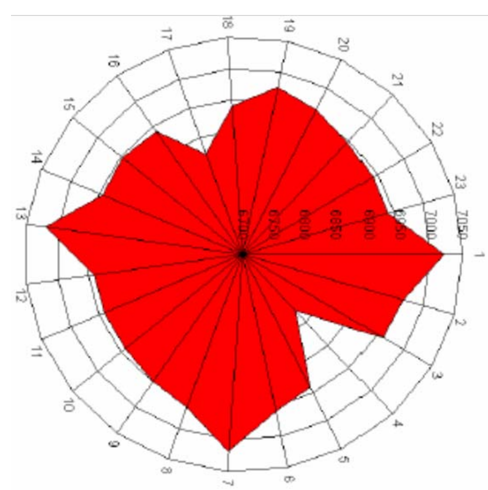
PROGRAM B

Results

Resulting unbalance: .52 gms
Unbalance angle: NA

Unbalance is ~ .0074% of nominal blade weight.
Residual unbalance is improved.
Again, the 4-pole solution is obvious.

Distribution graphic



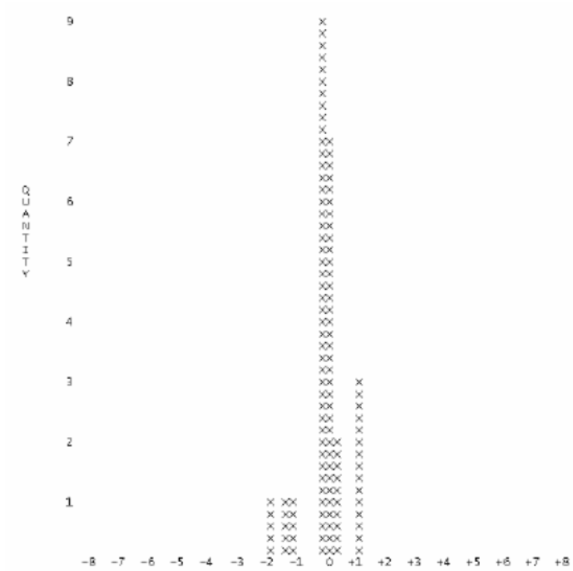
PROGRAM C

Results

Resulting unbalance: .09 gms
Unbalance angle: 251.4 degrees

Residual unbalance is again improved.
The histogram provided very basic information concerning the Blade Set.

Distribution histogram



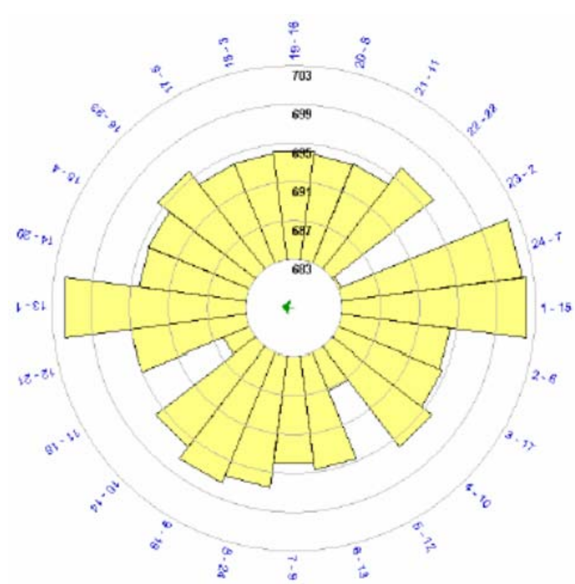
BALANCEPOINT 5.0

Results

Resulting unbalance: .008 gms
Unbalance angle: 110.5 degrees

Unbalance is ~ .0001% of nominal blade weight.
Lowest residual unbalance.

Distribution graphic



EXAMPLE 2 – 75 blades (Rolls-Royce Trent 500 First Stage HP Compressor)

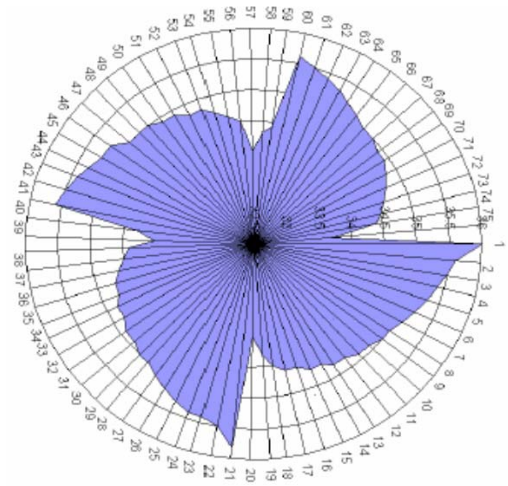
PROGRAM A

Results

Resulting unbalance: .24 gms
Unbalance angle: 44.3 degrees

Unbalance is ~ .69% of the nominal blade weight.
The 4-pole nature of the data is
obvious in the graphic.

Distribution graphic



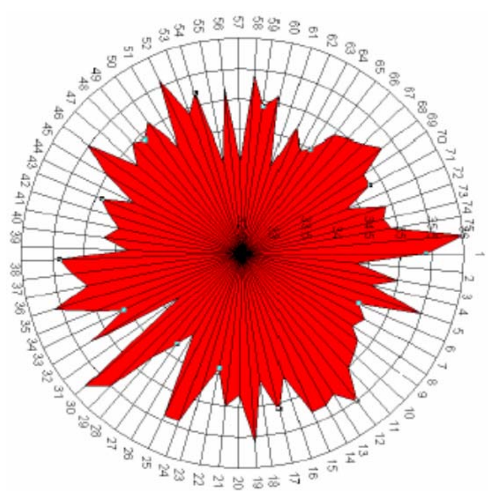
PROGRAM B

Results

Resulting unbalance: .086 gms
Unbalance angle: NA

Unbalance is ~ .25% of nominal blade weight.
Residual unbalance is improved.
Solution is much more randomized.

Distribution graphic



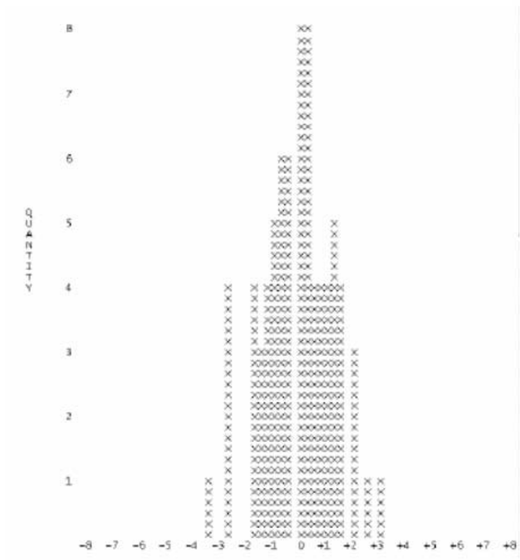
PROGRAM C

Results

Resulting unbalance: .09 gms
Unbalance angle: 251.4 degrees

Residual unbalance is again improved.
The histogram provided very basic information concerning the Blade Set.

Distribution histogram



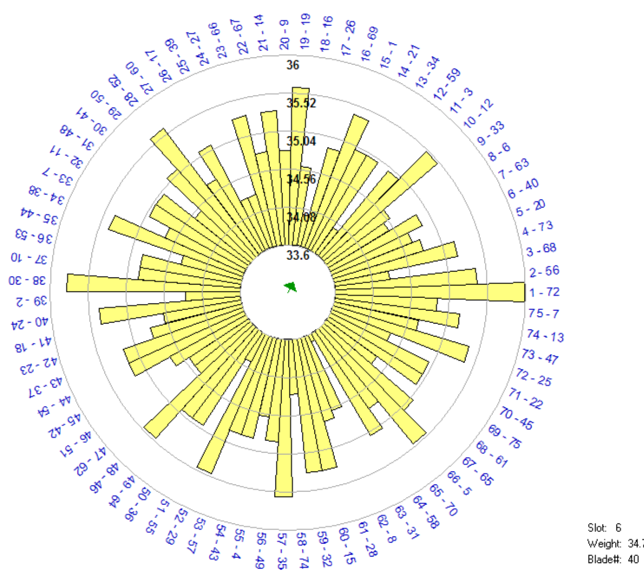
BALANCEPOINT 5.0

Results

Resulting unbalance: .001 gms
Unbalance angle: 114.7 degrees

Unbalance is ~ .003% of nominal blade weight.
Lowest residual unbalance.

Distribution graphic



Discussion

The results shown in Example 1 reinforce the need for balancing through blade placement optimization. Rotors with a small number of large blades that vary even a few percent in weight can very easily be assembled such that balance cannot be achieved with add-on weights. In this example the solution of the **Commercial Program B**, which has settled on a 4-pole solution, is a considerable improvement over the 4-pole Fixed Opposition solution of **Program A**. Both, however, exceed the .5-gram assembly tolerance for the engine. In these cases, in order to achieve a good balance, would have to substitute a number of similar blades from another set or send some of the heavier blades out for rework to lighten them. Both solutions would add considerable cost to the assembly process and base their solutions largely on guesswork.

The **Program C** solution improves the balance of the assembly considerably. The solution of the **BalancePoint 5.0** program has reduced residual unbalance to .008 grams, however – roughly 65 times better than **Program B** and quite acceptable for assembly.

In Example 2 the increased number of blades in the set would help to smooth the result of random placement – except that the blade set weight variation is 4.8%. This is a typical figure of blades of this size.

In the 4-pole **Program A**, the smoothing effect is offset by the weight variation. The result is three times that of Commercial **Program B**. **Program C** improves on the result of **Program B** by 35%. Once again the fast settling Heuristic of **BalancePoint 5.0** provides the best blade placement, achieving a balance that is 45% better than **Program B**, and important consideration considering that this compressor may be turning at nearly 20,000 RPM in normal usage. Then with 2.46 x 10 ^ 109 possible combination, the **BalancePoint 5.0** calculation time was less than one second.

For additional information about BalancePoint 5.0 or BalancePoint 3D contact:

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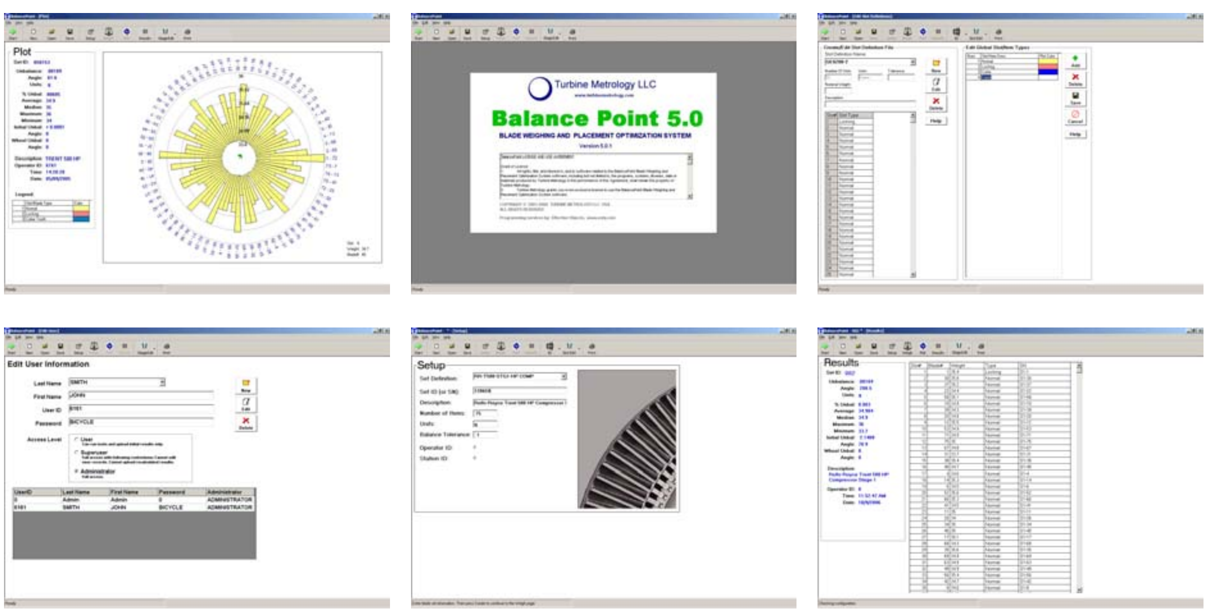

Example BalancePoint 5.0 screens