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Tracking and Dynamic Balancing of Rotor Blades

A Computerized Approach for Helicopter Blades Tracking and Balancing

Balsher Singh, Manoj Kumar R, Mohammad Nazim Siddiqui, Shiva Barpete
UG Students
Department of Aeronautical Engineering
Acharya Institute of Technology
Bengaluru – 560107, India

***Abstract*- Balancing a rotating component is critical in any mechanism. Devoid of proper balancing, any vehicle – be it in air, land or sea, will be severely affected by instability, uncontrollability and safety concerns. Imbalance of the helicopter rotor system leads to vibrations in the entire aircraft and may cause accident. This not only causes inconvenience to the pilot but also reduces the life span of the helicopter. Balancing procedure for the rotating mass is conducted to reduce the vibration. The focus of this project is to minimize the time required to balance the rotors and to make the balancing procedure more accurate, reliable, less time consuming and cost efficient by developing a computer program. Various algorithms are developed individually for main and tail rotor blades as per the sensitivity of the helicopter rotor blades. Using MATLAB software, some user defined functions are created and the entire algorithm is developed into a complete MATLAB code. The complete program is masked with a very user friendly GUI (Graphical User Interface). This program is designed to give a comprehensive balancing solution for both main and tail rotor at various flight regimes i.e. Ground condition, HOGE condition (Hover Out of Ground Effect), Cruise speed (160 kmph) and Maximum Flight speed (220 kmph). This program suggests the balancing corrections to be applied on the particular rotor blade(s) like mass correction, trim tab correction and pitch link correction. The balancing corrections suggested by software and the designer suggestions are found to be very close, this gives the validation of this program. The results indicate that the proposed method improves performance according to several criteria representing various aspects of track and balance. In future, helicopter acceptance will impose very low vibration levels to provide more comfort, stability and minimum noise in the cabin, also weapon platform stability in military purpose. The computerized approach will speed up the balancing process and bring down the vibration levels to desirable flight conditions.**

Keywords— Helicopter rotor blades, Vibration, Tracking, Balancing.

I. INTRODUCTION

Balancing is a key issue in aircraft design especially for rotating parts. Apposite and clear-cut balancing of aircraft parts and components are vital for aircraft stability and performance. This research focuses on conducting an extensive study on the tracking and dynamic balancing of the Helicopter main and tail rotor blade system. There are many causes for helicopter vibrations such as rotors, shaft gears, engines. These vibrations have an almost constant frequency due to the constant speed of rotating parts. The frequency range for comfort is from a few Hz to a few hundred Hz. In forward flight, the air-load on the blades varies during rotation due to the relative wind and incidence imposed by pitch. The loads on each individual blade are periodic at the frequency, which is a multiple of one-per-rev. The dynamic response of the blade is dependent on the fundamental blade characteristics like blade natural frequencies, damping and mode shapes. The dynamic loads can be amplified or attenuated by the blade dynamics and transmitted to the rotor hub. Each blade is still slightly different from the other and cannot be fitted to the aircraft before being balanced. All can have consequences on the dynamic behavior and on cabin vibrations. Vibrations levels and their association produces a beating phenomenon at low frequency, which can be disturbing for the crew.

Vibrations in helicopters result in: Crew fatigue, increased fatigue of mechanical parts, higher probability of avionics malfunctions and potential limits on the operational envelope.

Main rotor vibration can be characterized as either vibration that is inherent due to the asymmetric nature of rotor dynamics in forward flight (present even with identical blades), and vibration due to the non-uniformity of the blades. The non-uniformity is due to the variation in manufacturing, and uneven wear/fatigue of the blade as a result of usage. Manufacturing errors or various damages can induce blade dissimilarities. Many inspections are made at each manufacturing stage (weight, mechanical properties, mold temperature, holographic inspection). Each blade is still slightly different from the others and cannot be fitted to the aircraft before being balanced. Blade defects may be of different types: weight, span wise and chord-wise e.g. position, span-wise weight distribution, airfoil shape, blade twist, leading and trailing edge shape. All can have consequences on the dynamic behavior.

First, all blades must have the same first moment of inertia. This adjustment is made on scales and must be very accurate to obtain the same centrifugal force for all blades. Adjustment weights are added to the blade tip along the pitch axis.

Helicopter track and balance is the process of adjusting the rotor blades to reduce the aircraft vibration and the track spread of the rotor blades. Track and balance as applied to the helicopters is performed as follows. For initial measurements, the aircraft is flown through the different regimes during which measurements of rotor track and vibration are recorded. Rotor track is measured by optical sensors which detect the vertical position of the blades. Vibration is measured in the cockpit of the helicopter at the frequency of once per blade revolution (1per rev) by accelerometer, attached to the side of the cockpit. The flight regimes in are: ground, hover, 80 knots, and 120 knots. The three ways to balance the aircraft are: length of pitch change rod, tabs and weights on rotor sleeves. Track tuning often requires some compromise between hover and forward flight. Balancing also requires compromise, a perfectly hover-balanced rotor may cause problems in forward flight since all defects are corrected by weights but all type of defects do not create the same imbalance for the whole speed range.

This balance methodology is well adapted to current helicopters. For future high speed and low vibration aircraft, we should analyze whether this methodology is to be improved. So after the study of traditional balancing methodology, it seems it is very cumbersome, lengthy and time consuming. To overcome these drawbacks, we developed algorithms, which are transformed into a program which computerizes the whole balancing procedure. This computer program works on MATLAB software and it consists of several user defined functions like correction function, polar representation function and many inbuilt functions. This program has ability to give detailed suggestion about balancing correction in all the flight regimes to make this program more user friendly it is formed into a Graphical User Interface (GUI). This makes the visualization and understanding of the polar chart and the suggestions very comfortable. The suggestion by the software are very similar to that of designer's correction, this validates the accuracy of the program and proves its reliability.

II. SOURCES OF VIBRATION

In a helicopter, the source of vibration is either aerodynamic or mechanical. There are three sources of vibration in a helicopter:

1) Rotor Sources. These include the main and tail rotors.

2) Component Sources.

The drive shafts and gears in the main, auxiliary, intermediate and tail gear box, engine shafts and gears, component drive shafts.

3) Sources not related to rotors or components. These are usually a result of aerodynamic excitation of structures at their natural frequency.

Rotor sources

The main rotor is the primary source of vibration in a helicopter. Each main rotor blade is an aero foil section, which produces lift. Aerodynamic conditions that change as the blade rotates generate dynamic loads. The frequencies of these loads relate to the number of blades and the speed of rotation (blade passing frequency).

Irregular properties related to specific blades can result in vibration at 1R. Examples of irregular properties are

i) Small differences in the blade mass or center of gravity.

ii) Wear and damage that can cause small changes in the aerodynamic shape of the blade resulting in different lifting forces.

iii) Different angles of incidence because of small differences in pitch control rod load.

Component Sources

This covers a large number of components operating at different speeds and hence results in vibration at different frequencies. Usually, these components are balanced and aligned when they are manufactured or assembled. High vibration levels can occur if components become worn, damaged or go out of alignment. Debonding of composite and elastomeric components can also result in high vibration.

Gearboxes

The position of the gear teeth on a gear can change for different gears because tolerances can add together or subtract when a component is made. As a result, load on the tooth can change at different points as the gear rotates. Change in the load due to changes in attitude and airspeed are transmitted through the shafts to the support bearing where they are felt as vibration. This vibration occurs at gear meshing frequency.

Engines

The helicopters powered by Turbo-shaft engines, which do not have reciprocating parts, normally operate with low levels of vibration. But the vibration, which occurs when a shaft is out of balance, can be very large as it operates at a high speed. Causes for a shaft out of balance are-

i) Foreign object damage to compressor blades.

ii) Creep damage to turbine blades.

iii) Wear of bearings and seals.

Also, the accessories driven by engines can cause vibrations at specific frequencies if they are worn or damaged.

Unrelated Vibration Sources

Air flow over the helicopter can result in vibration at frequencies which are not related to rotor speed. For example, tail planes, fins, loose fairings can vibrate at their natural frequencies because of aerodynamic turbulence. Helicopters can also vibrate at their fundamental natural frequency because of aerodynamic turbulence.

III. PROCEDURE FOR TRACKING AND DYNAMIC BALANCING

Main Rotor

Balancing of helicopter rotor blades under centrifugal force field is called dynamic balancing, and is used to correct asymmetries due to mass, aerodynamic and structural behaviors.

Preconditions:

Main rotor blades to be statically balanced.

Carry out main rotor rigging. Identify a balancer and do to shift the balancer from the helicopter till dynamic balancing is completed.

Equipment required for balancing

- Velocity meters fitted on main gear box in y- direction.
- Velocity meters fitted on pilot side console vertical.
- Optical fast track mounted on nose.
- The Chadwick balancer analyser, signal selector.
- Magnetic pick up mounted on main gear box.
- Interrupter mounted on stub shaft along red blade.

Checks to be carried out on helicopter

- Ensure all velocity pickups are calibrated tightened and wire locked.
- Ensure the ferrite interrupter along red blade.
- Wire up the balancer analyser 8500C++ as per Chadwick Manual.
- Ensure that the connector outputs from the helicopter are connected to the signal selector as given below for 8500C++.

Environment conditions required for main rotor balancing

- Main Rotor balancing to be carried out less than 5 knots wind speed (preferable) on ground.
- Main Rotor balancing in forward flight to be carried out at a suitable height where there is less or no turbulence.

Sensitivity of main rotor correction:
Vertical Unbalance:

- Addition or removal of 60gms to 70gms changes the unbalance by 1 ips.
- Adding or removal from a blade will be in the ratio 2:3 i.e. addition/removal of 60gms means 24gms in forward trim chamber (leading edge) and 36gms in aft trim chamber (trailing edge).

Lateral Unbalance:

- One flat rotation (1/6 turn) to the track link changes the unbalance by 0.15 ips approx.
- Tab bending by 1 deg changes the vertical unbalance by 0.1 ips approx.
- Rotation of the track link by 1 turn changes the length of track link by 2mm (clockwise rotation looking from the top increases the length and vice versa)
- Track spread is the difference between the highest flying blade and lowest flying blade in mm.

Tail Rotor

1/rev unbalance of tail rotor is caused due to weight scatter on the tail rotor blade pair assembly or due to blades not rotating in the same plane. The unbalance caused due to weight scatter results in radial or in-plane unbalance of the rotor and vibration due to out of plane rotation causes the axial unbalance. There is also a cross sensitivity between the radial and axial unbalance.
Pre-conditions before dynamic balancing of rotor:

- The tail rotor blade pair has to be statically balanced.
- Tail rotor rigging to be carried out and all the blade pitch angles are to be almost equal and within the tolerances specified by the tail rotor rigging document. Ensure that the connector outputs from the helicopter are connected to the signal selector.

Sensitivity of tail rotor:
Tail rotor radial unbalance:

- Addition or removal of around 6gms (3gms Leading edge & 3gms trailing edge) changes the in plane or radial unbalance by 1 ips.

Tail rotor axial unbalance:

- If threaded eye ends are used, then 1 full rotation to pitch link barrel changes the axial unbalance by 0.2ips. The radial unbalance by rotating the pitch link by 1 full turn would change by 0.5ips.
- The cross sensitivity between radial and axial unbalance is negligible, thus when mass is added or removed to bring down the radial unbalance, the axial unbalance does not have a large change.

IV. TOWARDS COMPUTERIZED APPROACH

The focus of this project is to minimize the time required to balance the rotors and to make the balancing procedure more accurate, reliable, less time consuming and cost efficient by developing a computer program. Various algorithms are developed individually for main and tail rotor blades as per the sensitivity of the helicopter rotor blades. Using MATLAB software, some user defined functions are created and the entire algorithm is developed into a complete MATLAB code. The complete program is masked with a very user friendly GUI (Graphical User Interface). This program is designed to give a comprehensive balancing solution for both main and tail rotor at various flight regimes i.e. Ground condition, HOGE condition (Hover Out of Ground Effect), Cruise speed (160 kmph) and Maximum Flight speed (220 kmph). This program suggests the balancing corrections to be applied on the particular rotor blade(s) like mass correction, trim tab correction and pitch link correction.

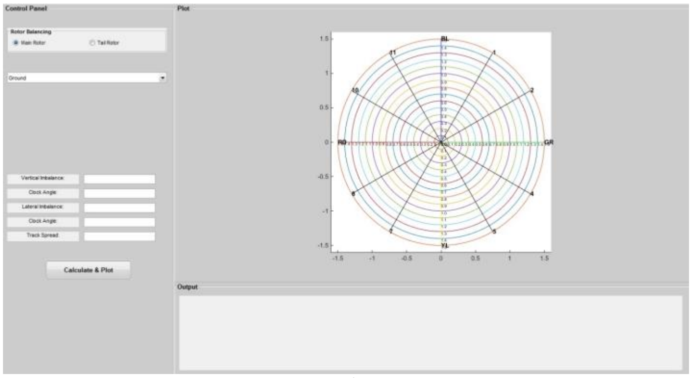


Fig. 1 Screenshot of program (GUI).

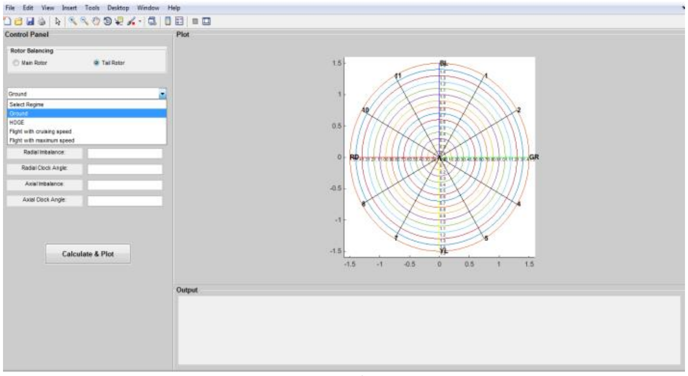


Fig. 2 Drop down menu for selecting regime.

The above image of program main screen shows the layout. On top left corner there are two radio buttons for selecting main rotor or tail rotor which is to be balanced. Below is the drop down menu which gives the user the option to select the flight regime at which the balancing is being conducted. Then there are the edit boxes where the values of vertical imbalance, clock angle, lateral imbalance (in case of main rotor) and axial imbalance, clock angle, radial imbalance (in case of tail rotor), can be given as an input to the program.

By clicking on the "Calculate and Plot" button, the values will be plotted on the chart and the resulting corrections to be applied on the blades will be shown in the output window.

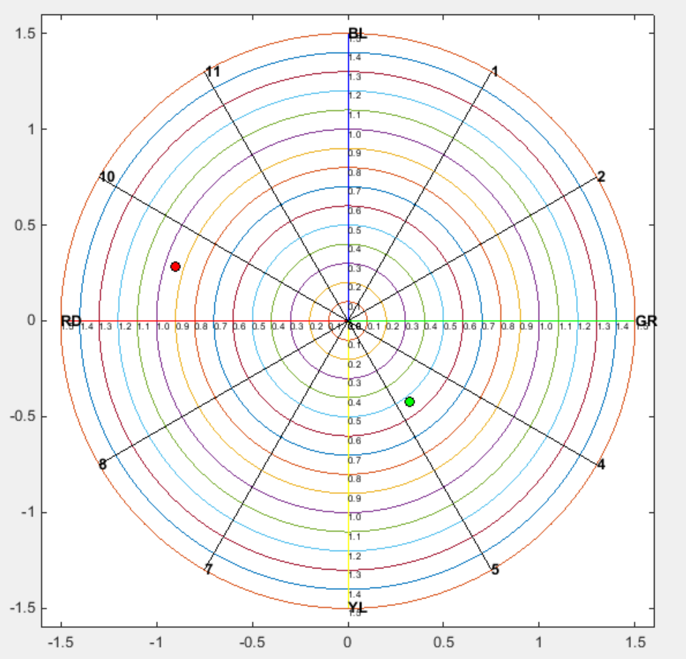
V. VALIDATION OF RESULTS

The imbalance values measured by the Chadwick balancer/analyzer are plotted by experts and suggestions are provided by them. The balancing corrections suggested by software and the experts suggestions are found to be very close, this gives the validation of this program. The results indicate that the proposed method improves performance according to several criteria representing various aspects of track and balance.

Ground Run 1

Main Rotor

Position	Amplitude (ips)	Phase
Vertical	0.531	4.45
Lateral	0.945	9.35
Track Spread(mm)	4	

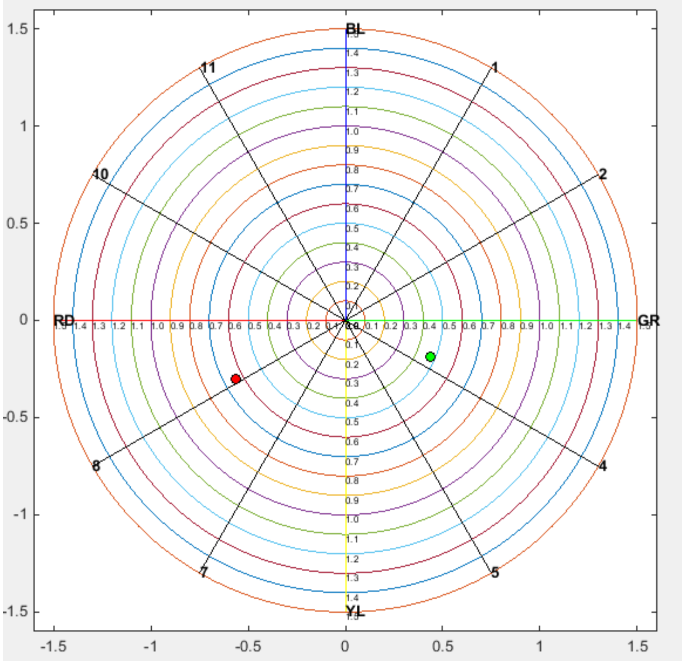


Designer's Solution –
Adjust Yellow blade track link by 1.75 flats.

Solution by the software –
Solving for track solution with track link only
Apply Lateral correction to yellow blade
Tab Bending (in Degrees): 5.310000
Track Correction (in flats): 1.694915

Ground Run 2
Main Rotor

Position	Amplitude (ips)	Phase
Vertical	0.476	3.47
Lateral	0.639	8.04
Track Spread(mm)	2	

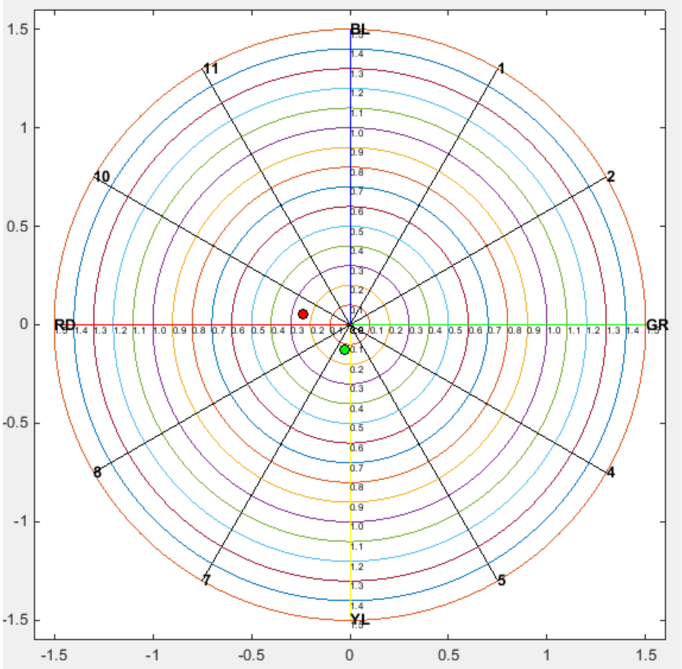


Designer's Solution –
Adjust Green blade track link by 1.75 flats.

Solution by the software –
Apply Lateral correction to Green blade
Tab Bending (in Degrees): 4.760000
Track Correction (in flats): 1.890756

Ground Run 3
Main Rotor

Position	Amplitude (ips)	Phase
Vertical	0.131	6.24
Lateral	0.242	9.29
Track Spread(mm)	2	



Designer's Solution –
Ground balance conditions satisfied

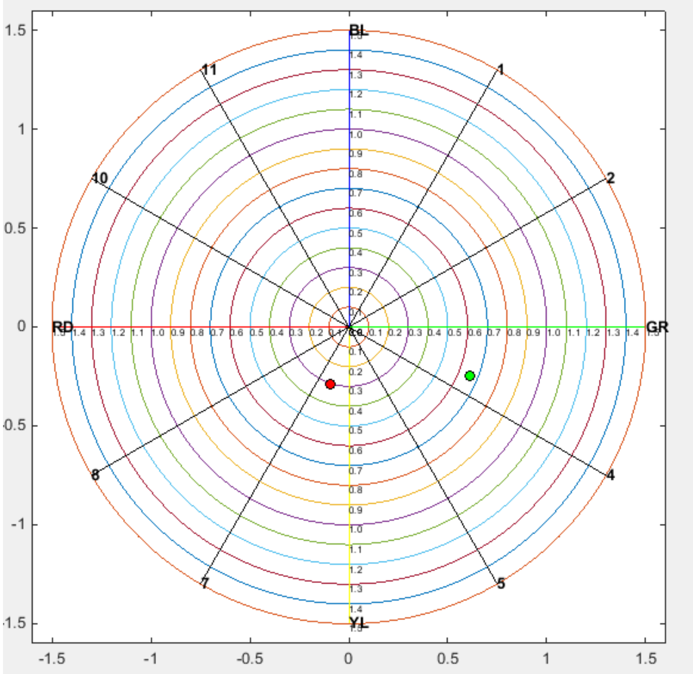
Solution by the software –

--Blades are balanced in Ground Run—

--Proceed for HOGE—

Flight Run 1
HOGE (Hover Out of Ground Effect):
Main Rotor

Position	Amplitude (ips)	Phase
Vertical	0.658	3.44
Lateral	0.302	6.36

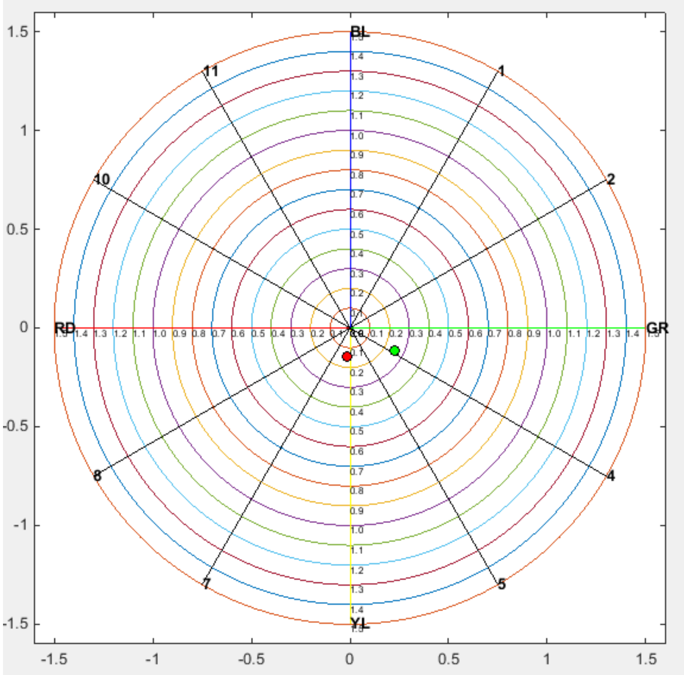


Designer's Solution –
Adjust Blue blade track link by 1 flat.
Adjust Green blade track link by 0.5 flat.

Solution by the software –
Solving with track link & mass solution
Apply Lateral correction to Green blade
Tab Bending (in Degrees): 6.580000
Track Correction (in flats): 1.367781
For lateral correction add 19.63 grams to yellow blade
7.85 grams => forward trim chamber, 11.77 grams => aft trim chamber.

Flight Run 2
HOGE (Hover Out of Ground Effect)
Main Rotor

Position	Amplitude (ips)	Phase
Vertical	0.253	3.53
Lateral	0.145	6.14

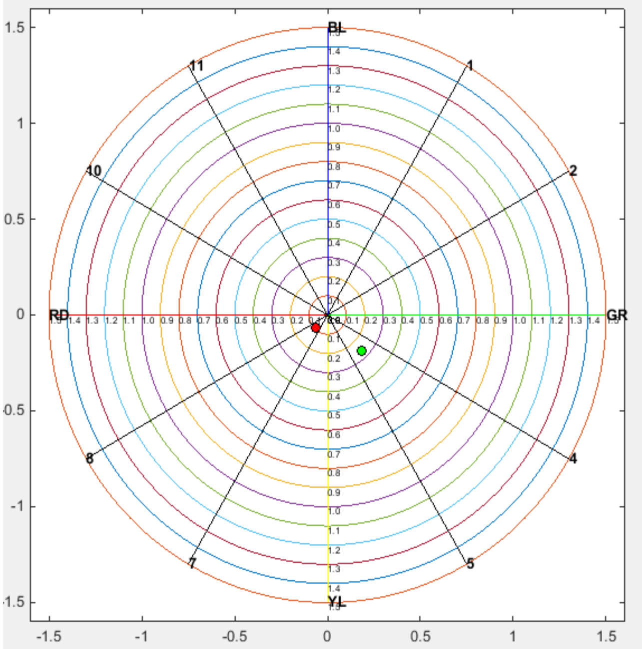


Designer's Solution –
HOGE balance conditions satisfied

Solution by the software –
--Blades are balanced in HOGE—
--Proceed for 80 Kias—

Flight Run 1
Cruise Speed (80 Kias)
Main Rotor

Position	Amplitude (ips)	Phase
Vertical	0.261	3.32
Lateral	0.091	7.29

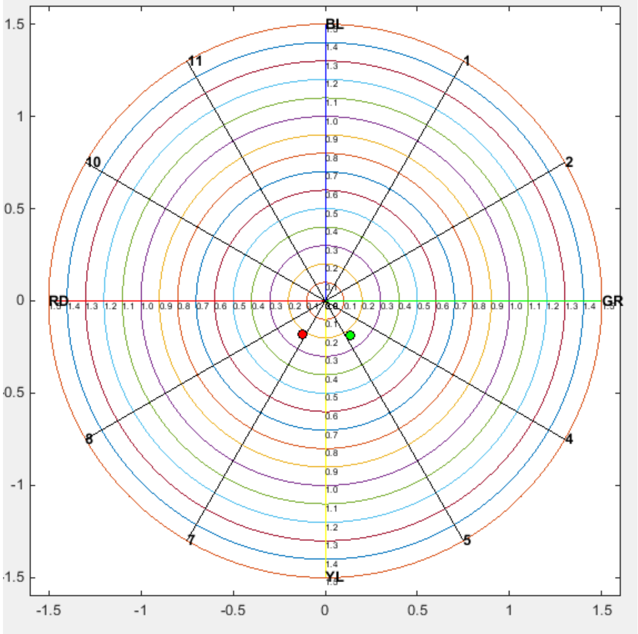


Designer's Solution –
Cruise speed balance conditions satisfied.

Solution by the software –
--Blades are balanced in 80 Kias—
--Proceed for 120 Kias—

Flight Run 1
Maximum Flight Run (120 Kias)
Main Rotor

Position	Amplitude (ips)	Phase
Vertical	0.219	7.10
Lateral	0.233	4.48



Designer's Solution –
Maximum Flight speed balance condition satisfied.

Solution by the software –
--HAPPY FLYING—

In similar way tracking and balancing for the tail rotor is also achieved. The balancing correction given by the software are implemented by the ground crew, this process is repeated until both main rotor and tail rotor are brought in same track and are successfully balanced.
Hence, in this way the helicopter rotor vibration levels are reduced to minimum.

VI. CONCLUSION

In this work, we present a methodology to minimize vibration on a helicopter for the purpose of developing, testing and, ultimately, improving Rotor Track and Balance (RTB) performance. A method is introduced for helicopter track and balance that can incorporate the prior knowledge of the system in the form of sensitivity coefficients between the blade adjustments and aircraft vibration. This MATLAB based Rotor Tracking and Balancing software with GUI provides correction suggestion quickly, consistently and reliably. The results obtained are much closer to the balancing correction values given by the designer, which shows the software's accuracy and efficiency. The results obtained with actual track and balance data indicate superior performance according to several performance measures. The results indicate that the method requires fewer iterations than those actually performed during the rotor balancing process, provides adjustments with a higher probability of success, and provides adjustments at the first iteration that are close to actual cumulative adjustments of several iterations performed during the rotor balancing process. This computerized approach require less time and effort rather than the manual approach. All these provide assurance about the comprehensiveness of the method's solutions. This method offers the versatility to be readily customized for all helicopters for which a record of accurate sensitivity coefficients exist.
In future helicopter acceptance will impose very low vibration levels, high stability and comfort inside the cabin, this can only be achieved when balancing process becomes automated to be accurate enough and fast for which computerized approach is required, this is where our tracking and balancing software finds its importance.

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