SHAFT TESTING APPARATUS
Shaft flex loading, flex load matching
Shaft spring rate, Flex zone profiling
spine and detection
Introduction:
This instruction manual is written primarily for clubmakers that are already familiar with shaft analysis theory and practice and would like to take advantage of the capabilities built into the Auditor SFA "Shaft Flexure Analyzer" to gain a better understanding of a shaft's characteristics and how to apply them for building better golf clubs.

The key to using the Auditor SFA successfully, hinges on developing a systematic and consistent methodology to shaft testing & Cloning, which will be clearly explained in the following sections.

Before getting started!
1- Your Auditor SFA is a precision instrument, so please handle it accordingly.

2-To make full use of the built in capability of this devise its important that you familiarize yourself with the functioning of the various components, especially the built in functions of the control module.

3-Shaft preparation prior to testing is an integral part of using the machine efficiently and will minimize tear and wear as well a the potential for breaking shafts “accidentally”

Last and not least read this manual to the end. Thank you!

Pre installation check list:
Unpack the Auditor SFA and make sure that the following items are included in the box:
-48 Inch Aluminum track
-Control module with the load sensing pod.
-Reference Pod assembly
-Shaft Tip deflection pod assembly
-AC/DC power adapter
-Lug screws for fixing the track to a bench
-Shaft rotation dial indicator
-RS-232 to USB adapter (Design may vary)
-RS-232 to RJ-11 Adapter and cord
-Shaft profiler installation disk
-This instruction manual!

Please note!
The Control module and pods are mounted on to the track once the track has been secured to the work bench with the lug screws provided.

Installation:
1-The Auditor SFA is best located on a sturdy uncluttered bench and about 25 cm (10 inches) away from the edge to facilitate access.

2-To prevent the risk of Electromagnetic interference (EMI), the Auditor SFA should be placed away from power tools such as grinders shaft cutters etc...

3- For ease of use and to reduce the risk for potential injuries, the Auditor SFA should be bolted on to the bench with the lug screws provided.

4-To Mount the control module & pods on the the track follow the instructions on next page...
Pods & control Module Installation

A quick examination of the control module and pods before mounting them on to the track is recommended, noting that the installation is easier to carry out when the track is bolted onto the bench!

1.1

Reference Pod Installation (1.2)
1-Loosen the T-nut by backing up the thumb screw few turns to increase the clearance between the pod and nut.

2-Align the Pod with the front of the T-nut aiming towards the track and slide forward gently until it engages fully.

3-Align the mark at the Pod base 1 inch from the track end using the ruler as a guide. Tighten the thumb screw to secure the pod.

1.3 The reference pod is seldom moved about the track and thus, it is used to reference the butt end of the shaft when it is against the pivoting back stop.

1.4 Tip Deflection Pod Installation (1.4)
1-Loosen the T-nut by backing up the thumb screw few turns to increase the clearance between the pod and nut.

2-Align the Pod with the front of the T-nut aiming towards the track and slide forward gently until it engages fully.

1.5 The deflection pod height is adjusted as a function of the amount of deflection needed to induce a desired load. It is however more practical to set the height and measure the induced load, which is more accurate and substantively faster.

Deflection is read directly at the pod with an accuracy of 0.5 mm

1.6 Shaft span length at the test point is read directly from the ruler, and originates at the reference pod (0).

1.7 The shaft stop on the reference pod is convenient tool for marking shafts during sorting and flex matching.
The Auditor SFA control module is the heart of the machine and careful attention and a good understanding of its capability will ensure that the measurements taken are precise without sacrificing speed or accuracy.

Before getting started:
1-Special attention must be paid to the load sensing module which, if subjected to high or sudden overloads may result in the load cell to be damaged beyond repair.

2-Shafts in general and graphite shafts more particularly are prone to stress induced "micro cracks" resulting from a breakdown of the epoxy graphite matrix due to localized stresses caused by excessive deflection. Micro cracks are responsible for a loss of modulus and a degradation of performance of the shaft.

Control Module positioning (1.1 & 1.2)
Unlike other shaft analysis instruments, the control module can be positioned anywhere along the 48" track to suit the experimental setup and method for each type of analysis that can be performed on the Auditor SFA.

To Lock and unlock the control module
Locate the lever at the back of the load sensing module and pull outwards to release.

Push the module along the track to the desired position. Push the lever to lock. Pushing hard on the lever is not necessary to secure the control module in place.

Sensing module height adjustment (1.3)
The purpose of the height adjustment on the load sensing pod is solely for leveling the shaft to compensate for shaft taper. Adjusting the sensing pod height to increase shaft deflection is not necessary neither recommended, except for shaft spinning.

The sensing pod is at the correct height when the control module is positioned 5" away from the track end which is adequate for most setups (1.4); the shaft tip must lightly contact the roller bearings on the tip deflection pod when spun 360 degrees (1.5).

(1.2) The exact position of the load sensing pod in relation to the reference coordinate can be read directly from the window about the control module.
Shaft flexure profiling methodology

In order to obtain a meaningful set of measurements representative of a shaft’s bending profile, it is important to:

1. Standardize testing methodology so that results can be replicated.
2. Eliminate testing anomalies and inconsistent measurements to prevent data bias.
3. Present the measured data in a clear and standardized format to facilitate analysis.

These criteria are easily achievable regardless of the type of instrument used, as long as we have a coordinate system that fixes the effective shaft test span to a frame of reference that is easily traceable.

We also need a repeatable load inducing force/moment of a known magnitude that can be applied at a point on the shaft within the chosen frame of reference.

It must be noted that not all shaft testing machines operate on the same principle, and thus it is important to distinguish the shaft deflection modes associated with each design.

In the case of the Auditor SFA, the principle deflection mode is based on a cantilevered beam (Fig 1) created by an extension of a simply supported beam (Fig 2) due to the necessity of having to clamp the shaft at the butt end. From an analytical stand point both forms are analogous.

The Auditor SFA can also operate on a simply supported beam principle (Fig3) but is of limited practical use, since this method imposes extremely high loads on the shaft especially when measuring deflection over short spans.

![Diagram showing beam bending modes]

**Load, deflection and elastic limit**

When load is applied on to a shaft, the resulting bending moment and deflection are proportional with respect to EI. This implies that we can selectively and interchangeably chose to either load or deflect the shaft.

To facilitate data integration into the coordinate system, the shaft is divided into imaginary segments of equal length, starting at the origin and numbered accordingly, so that each ordinate represents a point on the shaft at which a measurement has to be taken. Thus 25

Thus segment “25” is 25’ away from the butt end, segment 30, 30’ away and so on... The length of each segment or increment is arbitrary, noting that each however smaller increments finer and more accurate.

**Load & moment**

The ordinate and the induced moment constitute a data pair denoting stiffness distribution over the (X,Y) which

The confusion between load and moment is quite likely an overlap of terminology and methods that are closely associated with the use of the “classic shaft deflection board”, where a weight of a known mass (the load) is hung on the shaft at some distance from the butt. The resulting deflection (D) measured in inches, is proportional to the shaft’s bending stiffness (EI)*

![Shaft deflection board with hanging weight]

**Segments, increments & Slope**

With the coordinate system and the bending moment so defined, it is now easy to realize that what is being measured when a shaft is “loaded” at a point along its length, is in fact a bending moment relating to a segment or span, originating at the fulcrum. The measured moment is also proportional to the bending stiffness (EI).

Thus by selectively taking additional measurements at each increment, we are effectively “mapping” the bending stiffness of successively longer spans.
 Shaft spine survey and analysis

1. Release the break on the control module. (2) Slide it on the track to a position that is about half the shaft length to be tested and lock the pod in position. (3) Next reset the front pod height to 0. (4) Do the same for the center pod. (5) Turn the control module to ON and wait for the module to finish booting. (6) Insert and tighten the dial indicator on the shaft to be analyzed. (7) Mount the shaft as rigged on the Auditor SFA, with the dial indicator clear of the back pod finger stop.

5. (8) Raise the center pod by a small amount enough to deflect the shaft... Depending on shaft flex and beam span a deflection of 19–25 mm (0.75”–1.0”) is adequate for wood shafts, 19mm (0.75”) or less for iron shafts is recommended. (9) Rotate shaft by a turn and let go. The shaft auto rotates to a position of least resistance. (10) Adjust the dial to zero and mark the position on the shaft with a pen. (11) Reset the Auditor control module to Zero. Do not remove the shaft at this point...

Please note:
Up to this point, the setup described above is used to force the shaft in its neutral bending position, which is the position of least rotational resistance. The load value displayed comprises the weight of the shaft and dial indicator as well as the load applied to it by the induced deflection height set by the center pod.

By setting the tare to zero, an initial "at rest" condition is established. Any disturbance from this at rest position to a position of maximum rotational resistance can be measured in the form of a differential measurement.
Shaft spine survey and analysis

Locating the shaft spine and quantifying its "relative strength"

A spine as it relates to a homogeneous shaft of symmetrical circular cross section, is a feature characterized by a shift of the neutral axis from its centroid position, brought about by un-even longitudinal bending stresses.

Un even bending stresses are the un-intended consequence of manufacturing processes, and the build up of residual stresses arising from the curing process at elevated temperatures (graphite shafts) or heat treating in the case of steel shafts.

A shift in the neutral axis from the geometric center of the shaft (centroid position) has a deleterious effect on performance which manifests itself in the form of asymmetrical bending properties, dynamic instability, and an overall lack of consistency.

Rolled graphite shafts are particularly susceptible to exhibiting a plurality of spines, due to the overlap of layers upon layer of material, and the build up of residual stresses arising from the curing process at elevated temperatures.

When subjected to bending, the layers at the over-side of the shaft are compressed while the layers of material at the underside are stretched. Any stress imbalance resulting from the fault line(s), between the underside and overside of the shaft, produce a torque that induces a rotation about the neutral axis, offering the least rotational resistance.

This equilibrium position, places the strongest spine below the neutral axis and any attempt to rotate the shaft from that neutral resistance is met with resistance by an order of magnitude.

Peak turning resistance reaches a maximum when the weak side is opposite the starting position.

Neutral position weak side up (Position of least resistance)

Resistance to turning increases as the shaft is rotated away.

(10) Zero the control module and to Tare the load. (11) rotate the shaft slowly up to a maximum peak load. Mark this position on the shaft.
Flex zone profiling

Flex zone profiling is a new technic developed for evaluating the playability of golf shafts, since it is possible to have two shafts with the same nominal stiffness but with entirely different playing characteristics. This to facilitate comparison between shafts. The flex load curve is plotted at regular intervals starting at the tip moving toward the butt of the shaft. This is how to develop a flex load curve.

Locating the shaft spine and quantifying its “relative strength”

A spine as it relates to a homogeneous shaft of circular cross section, is a feature characterized by a shift of the neutral axis from its centroid position, brought about by an uneven stress distribution when the shaft is subjected to a bending load.

By a “ridge” or “fault line” extending over the length of a shaft and affecting its bending behavior in a deleterious and non-symmetrical way.

This spine is the unintended consequence of the manufacturing processes, material(s) selection and geometry that went into its making.

Rolled graphite shafts are particularly susceptible to exhibiting a plurality of spines, due to the overlap of layers upon layer of material and the build up of residual stresses arising from the curing process at elevated temperatures.

When subjected to bending, the layers at the over-side of the shaft are compressed while the layers of material at the underside are stretched. Any stress imbalance resulting from the fault line(s), between the underside and over-side of the shaft produces a torque that induces a rotation about the neutral axis, offering the least rotational resistance.

This equilibrium position, places the strongest spine below the neutral axis and any attempt to rotate the shaft from that neutral resistance is met with resistance by an order of magnitude.

Coordinate System, Segments & Increments.

The established analytical methods dealing with beam bending place the coordinate system needed to “frame” the position and magnitude of a force from the origin \((X_0)\) to the left at the butt end of the shaft and extending towards the right. The \(X\) axis is used to reference the position of the force acting on the shaft measured from the butt end.

The bending moment created by applying a force \(F\) at a distance \(L\) from the fulcrum \(P\), \((M=FxL)\) is what’s casually referred to as “bending load”, “shaft load” etc... This can be confusing since a clear distinction between the applied force and the resulting moment cannot be easily distinguished first hand!
*************** SPINETALK TERMINOLOGY AND DEFINITIONS (Version 2) ***************

1. The terminology and definitions relate to the standard method of spine finding (Colin’s or similar) where the shaft is rotated whilst under tension at both ends, resulting in a vertical bend, flexing in the downwards direction.

2. The high spot of a speed bump (crest of a ridge) is marked on the top of the shaft with a line and the letter "S". This point should be referred to as “S--” (for Spine). If there is more than S position, then they should be marked “S1--”, “S2--”, “S3--” etc ….. in order of the level of resistance encountered as YOU TURN THE SHAFT TOWARDS THE HIGHEST POINT OF THE SPEED BUMP. In other words S1-- will have the highest level of rotational resistance as you rotate the shaft TOWARDS the high spot of the speed bump. It will probably also have the LEAST level of rotational resistance as you turn the shaft AWAY from the high spot of the speed bump.

3. When a shaft is placed under tension in a spine finder it will tend to take up a position of stability. Slight rotation of the shaft away from this position will meet with resistance in either direction. Unlike the S position, on removing the rotational force the shaft will try to rotate BACK TOWARDS THE STARTING NEUTRAL POSITION. This position should be marked on the top of the shaft with a line and the letter "N" (for Neutral). This point should be referred to as “--N”.

4. For a single S steel shaft, N-- will generally be located at 180 degrees from S-- on the other side of the shaft. For a double S graphite shaft, N-- will generally be located midway between S1-- and S2--.

5. If there is more than one neutral position, then they should be marked "N1--", "N2--", etc ….. in order of the level of resistance that you meet as you turn the shaft in either direction away from the neutral position. In other words if there is more than one N position, N1-- should indicate the most stable shaft position with the HIGHEST level of rotational resistance as you try to turn the shaft away from that position.

6. The Natural Bending Position (NBP) of any shaft is the bend profile which offers greatest rotational stability. A single spine steel shaft will likely have N on the outside of the bend and S on the inside of the bend. This is a very stable bending position which resists rotation in either direction. To place S on the outside of the bend and N on the inside of the bend is an unstable position where the shaft is likely to rotate, often violently, in either direction under the least amount of rotational pressure.

7. When describing shaft orientation in a clubhead, reference should be made to a clock face. The point of reference is the toe of the club pointing towards 12 o’clock with the club in the playing position, facing the target line. We should also assume that we are the golfer, holding the club and looking down on the clubhead. When describing the shaft orientation in the clubhead we should state the position of S (or S1 in the case of multiple spine positions) in relation to the clock face. For example S1--3 would indicate mark S1 at the 3 o’clock position. Left handed players must convert their LH position to the equivalent RH position when reporting to Spinetalk, in order to avoid any confusion.

8. Before removing a shaft from a clubhead for spine finding, the original position in the clubhead can be noted by placing a line at the 12 o’clock position and labeling it "O" (for original). This mark can then be used to determine the original S or S1 position should you wish to report this to Spinetalk.

9. The position of one mark in relation to another can be reported as follows. "S1-180-S2" denotes two S positions on the same plane at 180 degrees from each other, as in the case of a typical double S graphite shaft. "S-180-N" denotes an S and N position on the same plane at 180 degrees from each other, as in the case of a typical steel shaft.

By doing so we are able to establish the rate at which stiffness changes from one contiguous span to the next. The slope so defined, describes the shaft’s “bending profile” over its length.

Data reporting
To simplify the mapping process and speed up data collection, the words integrated into the test span length, so that only the load position from the origin and the measured moment need to be reported for each span tested, assuming that a basic protocol has been established beforehand. Also in the case of the Auditor FSA, the (Y) axis represents either a load for a given deflection or a deflection for a given load. Testing a shaft to a constant deflection speeds up profiling greatly and yields more accurate results overall.