CENER

# Report: BTB.CENER.01

# Design and Supply of an Excitation System for Fatigue Testing of Wind Turbine Blades

# 1.- CONDITIONS FOR THE SUBMISSION OF OFFERS

## 1.1.- INTRODUCTION

### 1.1.1.- AIM

This document describes the functional requirements to be met by the Ground Based Exciter for FLAPWISE Fatigue testing long blades at the Blade Testing Facility of the Wind Turbine Testing Laboratory (L.E.A.) in Sangüesa (Navarra). The technical conditions to which the bidders will be subjected are also specified in this document.

The starting data for these user requirements come from the information resulting from the simulations of these blade tests.

### 1.1.2.- SCOPE

This specification aims to clarify the characteristics to be met by this Ground Based Exciter as well as the technical conditioning of the bid.

## 1.2.- GENERAL DESCRIPTION

The Blade Testing Laboratory has currently two load application systems for blade fatigue testing:

- “Blade Based Exciters” which are of "Resonant Mass" type. They are located on the blade and they are currently and specifically used in Fatigue Tests in EDGEWISE direction.
- “Ground Based Exciters” which are of "Resonant" type. They are located between the ground and the blade and they are currently and specifically used in Fatigue Tests in FLAPWISE direction.

Given the current development of ever-longer blades, the need has been identified for a "Ground Based" type exciter of greater load and displacement capacity for FLAPWISE fatigue tests. Although, the Exciter to be offered has to be focused on FLAPWISE fatigue tests, it has also to be adaptable for carrying out EDGEWISE fatigue tests.

Furthermore, in anticipation of BIAXIAL fatigue testing becoming more prevalent in the future, it is considered that this "Ground Based" type exciter has to be expandable to the extent that with small scale extensions is convertible to a exciter able of applying loads in FLAPWISE and EDGEWISE directions at the same time.

## 1.3.- SCOPE OF THE OFFER

Bidders shall offer integrated solutions that include the following tasks:

- Design and configuration of the excitation system and its components including the control system and the software with an easy to use human machine interface.
- Manufacture of components.
- Assembly.
- Supply and installation in Sangüesa (Navarre).
- Default configuration of the equipment for carrying out the target tests.
- Technical user's manuals: general, operating, handling and lifting, maintenance and storage.
- Training of CENER´s technical staff for the efficient and safe operation of the equipment in the following cases:
  - Predetermined standard tests, i.e., FLAPWISE fatigue tests.
  - New non-default tests where reconfiguration is required at both hardware and software levels.
- Commissioning of equipment during acceptance tests.
- Warranty, after-sales service and spare parts.
- Spare parts price list with a valid period of at least 3 years.

## 1.4.- DOCUMENTATION TO BE SUBMITTED BY BIDDERS

Offers must contain separately at least the following documents:

1. **Detailed technical description of the proposed solution.**
   The technical offer shall cover all aspects required in the technical specification for the supply and shall be divided into the following sections:
   - Exceptions to the request for an offer.
   - Lists, data sheets and full description of the features and performance of the equipment or services offered, as well as the list of technical data.
   - List the components included in the offer, hardware and software, specifying their manufacturer and model. Data sheets must be available.
   - List of technical documentation to be sent with the delivery.
   - Special tooling lists for assembly and maintenance of the excitation system.

- In the case of the provision of services, bidders shall include: the planned volume of hours, the list of persons and their professional histories, the planned schedule with their workload in man-hours and the hourly rates for each professional category.
- Schedule and delivery time.
- Engineering.
- Supply.

The tenders shall refer to the items included in the same way as in this specification. Any item or service that differ from those defined in this document shall be explicitly stated. Besides:

- A justification or pre-design of the proposed alternative must be attached, this presentation must include the main data of the offer.
- The loads supported by the excitor shall be specifically indicated as a function of test frequencies and dynamic displacements, see Section 2.3.1.- for further clarification.
- Fatigue design life of the elements offered shall be included.
- The supplier shall provide a list of recommended spare parts for critical items.
- A spare parts kit will be offered as an optional of the main supply, including the usual delivery time for each ítem.

2. Realistic **planning of activities**, taking into account the calendar of actions proposed by CENER.
3. **Description of warranties** for operating hours and **after-sales technical service** including lead times for the supply of spare parts.

## 1.5.- LEAD TIME

The target **LEAD TIME** for having the excitation system installed and accepted after commissioning at CENER's premises is **15 months** from signature of the contract. The Target date for the **supply and installation** in Sangüesa of the equipment is **12 months** from signature of the contract.

## 1.6.- PROJECT EXECUTION PHASES

During the execution phase of the project, CENER will designate an interlocutor who will collaborate with the project manager of the successful bidder. CENER's interlocutor will be responsible for providing the necessary information for the correct design of the excitation system.

## 1.7.- WARRANTIES, INSPECTION AND TEST

The supplier shall check and guarantee the correct and safe functioning of its supply in workshop tests and in field operation, and shall indicate all design and operation data in data sheets that has to be attached.

Software covered by this specification shall be warranted in writing against design and programming defects. The supplier shall repair or replace, at no extra charge, any defect in the object of its supply.

All inspections and workshop tests shall be carried out under the responsibility and at the expense of the supplier, and may be observed by CENER personnel.

The supplier shall deliver the corresponding test protocols and certificates.

The performance of the tests and inspections does not exempt the supplier from its responsibility for a possible defect in the design, programming and operation of the supply.

The inspection or acceptance of the tests by CENER does not exempt the supplier from the responsibility to replace at its own expense of any part that fails during installation, interconnection, start-up tests, commissioning, execution of commercial testing and maintenance works:

- This liability shall remain in force until the end of the warranty period.
- Failures caused due to design or programming defects are considered.

The warranty period will be established in a period of time and in hours of operation from provisional acceptance of the system pursuant to section 1.9 hereinbelow, since the system will not used continuously:

- Warranty in a period of time: **24 months** are required.
- Warranty in hours of operation: **4392 hours** are required.

The warranty will be expired either when the **24 months** period has been exceeded or when the **4392 hours** of operation have been exceeded, whatever comes first.

The warranty shall include both labour for repair, modification, and all necessary adjustments; as well as replacement at its own expense of any part that fails during the warranty.

## 1.8.- FINAL DOCUMENTATION TO BE SUBMITTED

The supplier shall deliver at least the following engineering documentation together with the whole delivery of the system:

- A design report of the excitation system. This report shall include the static and dynamic load that can apply as well as the loads that can withstand in the critical joints supporting the structure. Loads must be delivered in any axis and situation. This report shall consider the buckling design.
- Control and configuration programs.
- Tables of variables: inputs/outputs, emergencies, alarms and events.
- Operation manuals.
- Software:
    - Backup copy of the current versión.
    - Copy of executables for possible re-installation of the new versión.
- Test protocols and validation reports.

## 1.9.- ACCEPTANCE OF THE EQUIPMENT

During the weeks following the assignment of the order, CENER shall submit for approval by the supplier, an acceptance protocol that includes the validation plan, i.e., the set of tests and checks that shall be carried out to assess the suitability of the supply for the performance required. The supplier will introduce necessary modifications to the acceptance protocol. In any case, the acceptance protocol must be agreed and accepted by both parties.

The result of its execution must be positive, i.e. the objectives and tests indicated in the accepted protocol have to be fulfilled, and this fact will be considered a necessary milestone for making the payment corresponding to the delivery of the system. If the outcome of the implementation of the validation plan is successful, the parties shall sign the Provisional Acceptance Minute.

## 2.- TECHNICAL REQUIREMENTS FOR THE EXCITER

### 2.1.- DESCRIPTION OF THE FATIGUE TEST

#### 2.1.1.- BASIC CONCEPTS

The fatigue test consists basically of assembling a blade to a test rig, as shown in **Figura 1**, and applying an harmonic load of a given amplitude a certain number of cycles in a direction perpendicular to the blade's pitch axis. The exciter generating the load will excite the first mode of vibration of the system by applying an harmonic oscillating exciting force at the frequency, or very close to it, of the first mode of the system under testing. In this way, it will be caused the system to enter into resonance, and therefore, the required blade deflections will be achieved with a relatively low external energy input compared to other test systems. The exciter control system regulates the harmonic linear displacement in such a way that the desired amplitudes are achieved.

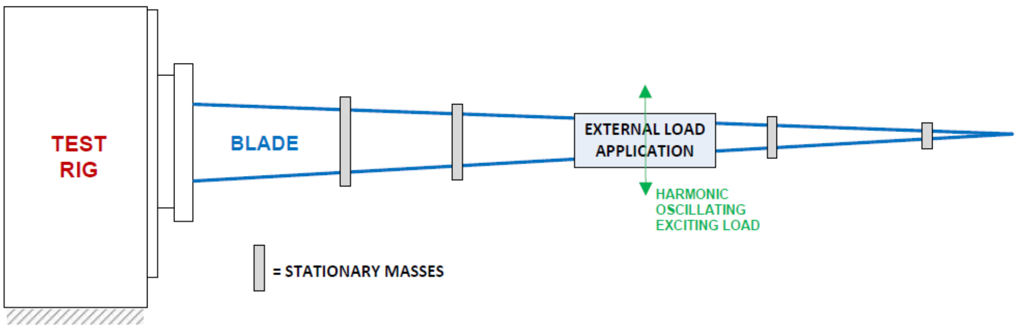


**Figura 1** General Setup of the Fatigue Test

Each test must be set up according to a target bending moment distribution. The exciter, together with the own weight of the blade itself and the stationary masses fixed along the blade, must generate a moment distribution as close as possible to the target bending moment distribution. The blade, due to its own weight and test tooling on it, is always preloaded to a specific mean bending moment value.

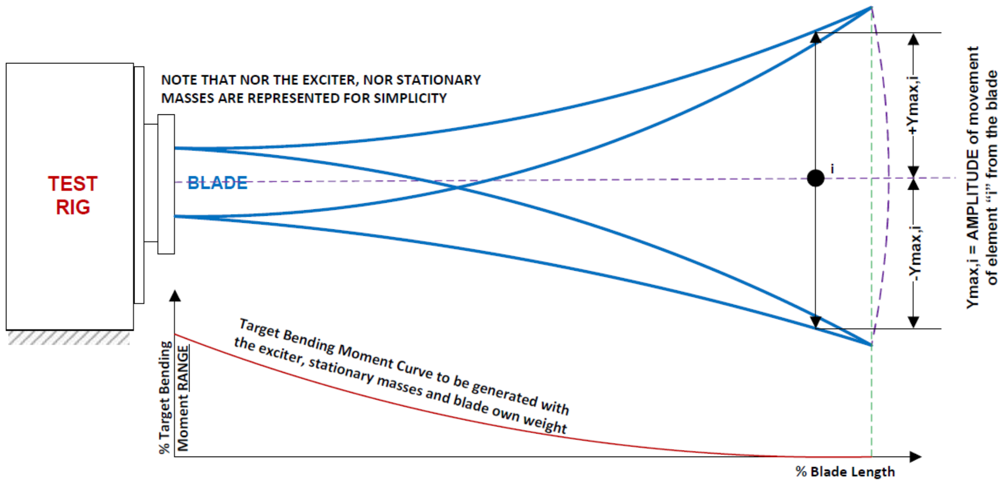


**Figura 2** Target Bending Moment Curve Distribution

**Figura 2** shows a cycle of the type of excitation force to be introduced by the exciter. The target bending moment **RANGE** distribution is made up of time instants of máximum amplitudes, "***+Ymax***" and "***-Ymax***". The real distributions obtained for these time instants should be as close as possible to the target distribution.

### 2.1.2.- CONFIGURATION OF THE FATIGUE TEST

Generally speaking, the vast majority of the blade fatigue tests that are currently performed all over the world can be classified in two groups depending on the load application direction:

- SINGLE AXIS excitation: load is applied in a single direction, being FLAPWISE or EDGEWISE direction most of the times.
- BIAXIAL excitation: load is applied in two directions at the same time, that is to say, in FLAPWISE and EDGEWISE directions at the same time.

There are more nuances that particularise each type of test but it is the direction that mainly determines what type of excitation is necessary to accomplish a certain test.

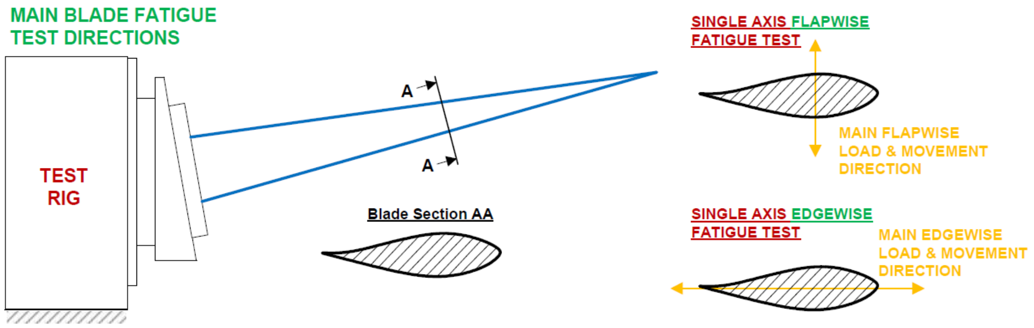


**Figura 3** Sketch of the MAIN fatigue test directions

It is the external exciter which applies load in a certain blade section and thus causes blade movements. In the case of the SINGLE axis excitation, the blade will mainly moved along the load application direction, either FLAPWISE or EDGEWISE. In the case of the BIAXIAL excitation, the blade movement will be a combination of FLAPWISE and EDGEWISE movements.

## 2.2.- <u>SCOPE</u>

It is intended to specify the minimum and essential technical specifications to be met by the "Ground Based Exciter" of "Resonant" type to be quoted for carrying out Fatigue Tests in FLAPWISE direction.

The scope of the main delivery does not only include the "Ground Based Exciter" **<u>SET</u>** as defined below, but also the software and hardware of the control system so as to run the whole system from a PC.

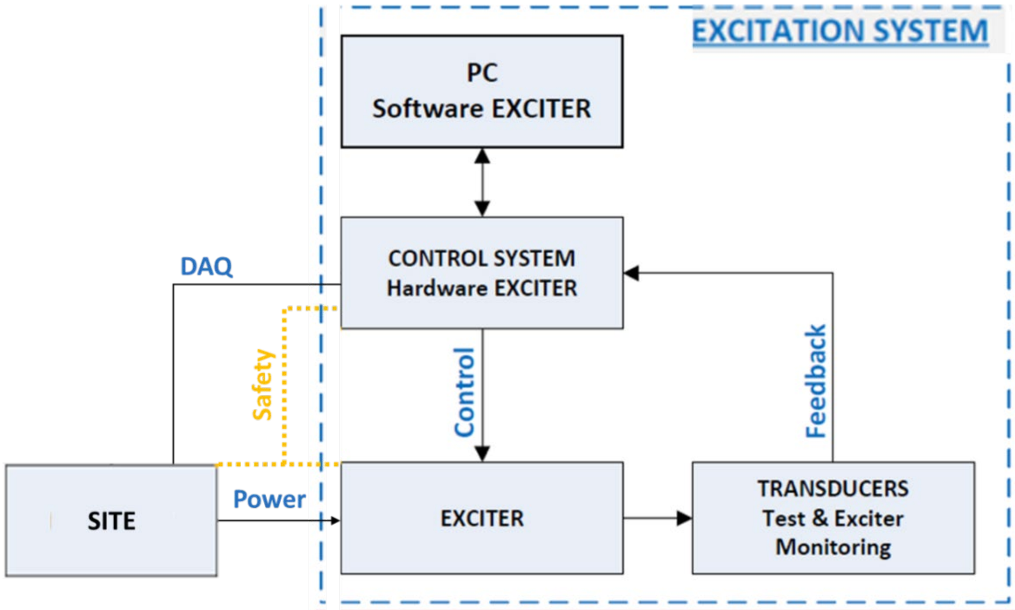


**Figura 4** "Ground Based Exciter" SET

The "Ground Based Exciter" **SET** to be quoted is a electro-mechanical system composed of next main parts: the exciter itself plus the self-supporting platform, swivel joints, rod and transducers for monitoring exciter related conditions of the test. See next sections for more detailed information.

The exciter to be quotted must be **electrical**.

## 2.3.- FUNCTIONAL SPECIFICATIONS FOR THE EXCITER

### 2.3.1.- LOAD, DEFLECTION AND FREQUENCY CAPACITIES

Next specifications are the result of a study so as to define the required capacity for the electro-mechanical exciter. This approach assumes the scenario in which only one load application point is used for performing the FLAPWISE fatigue test.

For Single Point Single Axis FLAPWISE fatigue testing, the exciter will be positioned between the ground and the blade as shown in next sketch:

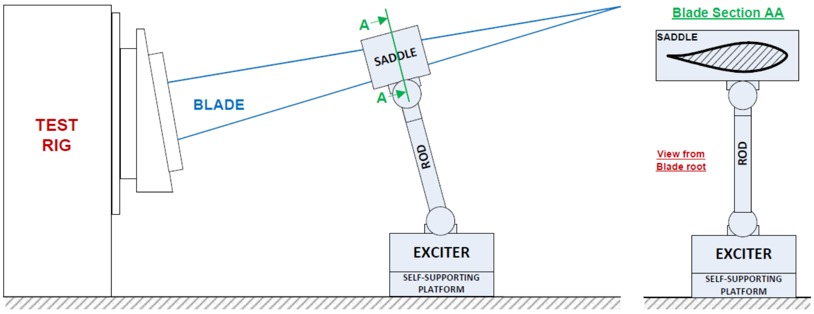


**Figura 5** Sketch of the mechanical links

Basic on above basic inputs, it is required an EXCITER with a MINIMUM capacity of:

- Dynamic effective **STROKE**: **0mm - 3000mm** (0mm - ±1500mm)
- RANGE of excitation working **FREQUENCIES**: **0.2Hz – 0.9Hz**
  *Remark: the **STROKE** and **FREQUENCIES** requirements do not need to be combinable in all ways. See required combinations of **STROKE**, **FREQUENCIES** and Dynamic **FORCE AMPLITUDE** in Table 1.*
- Static **FORCE** AMPLITUDE: **≥120kN**
- Dynamic **FORCE** AMPLITUDE in a blade fatigue test at RESONANCE, where in sinusoidal excitation loading FORCE and VELOCITY parameters are in phase:

| Test **DIRECTION** | Working **FREQUENCY** [Hz] | Dynamic **STROKE** [mm] | Dynamic **FORCE AMPLITUDE** [kN] |
|---|---|---|---|
| FLAPWISE | [0.3 - 0.5] | 1000 | ±120 |
| FLAPWISE | [0.6 - 0.7] | 1000 | ±95 |
| FLAPWISE | [0.3 - 0.5] | 2000 | ±65 |
| FLAPWISE | [0.6 - 0.7] | 2000 | ±45 |
| FLAPWISE | [0.3 - 0.5] | 3000 | ±40 |
| FLAPWISE | [0.6 - 0.7] | 3000 | ±30 |
| FLAPWISE | 0.35 | 1500 | ±120 |
| FLAPWISE | 0.35 | 2000 | ±95 |
| FLAPWISE | 0.35 | 2500 | ±75 |
| FLAPWISE | 0.35 | 3000 | ±60 |
| FLAPWISE | 0.45 | 1500 | ±95 |
| FLAPWISE | 0.45 | 2000 | ±70 |
| FLAPWISE | 0.45 | 2500 | ±60 |
| FLAPWISE | 0.45 | 3000 | ±50 |

**Tabla 1** Operating LOAD Cases when sinusoidal loading at resonance

### 2.3.2.- SELF-SUPPORTING STRUCTURE/PLATFORM

As there is neither strong floor nor that T-slot rails available on the ground for fixation of loading application devices, the exciter has to be delivered with a ***SELF-SUPPORTING STRUCTURE/PLATFORM*** to allow its positioning in any location of the testing hall by the use of steel ballast. The exciter shall be mounted and fastened to this structure and this platform will be directly supported on the ground and therefore, it has to assure a good contact with the lab floor.

Main features:

- Special attention shall be paid to its dimensioning as the blade testing hall has geometrical boundary conditions as shown in Annex 3.1.-, see Figura 9 and Figura 10 for more detail.
- Loads on the ground must be minimised as far as possible. The operating manual of the exciter must specify the required load-carrying capacity for the ground on which the system will operate.
- Depending on the load to be applied by the exciter, more or less dead mass will have to be necessary to place on the self-supporting structure so as to avoid any movement and/or slippage of the whole set:
    - A modular and easy mounting dead-masses system has to be offered.
    - The dead mass assembly should be composed of a set of equal masses that has to include all the necessary devices for easy lifting and handling maneuvres.
- The operating manual of the exciter must include the required amount of dead mass to safely operate the exciter.
- The kit of dead masses for the platform will be offered as an optional item of the main supply. Dead masses' geometry shall be agreed with CENER.

### 2.3.3.- ROD

The design has to be minimally composed by a bi-articulated ***ROD*** that connects the exciter with the blade through a saddle as shown in next sketch:

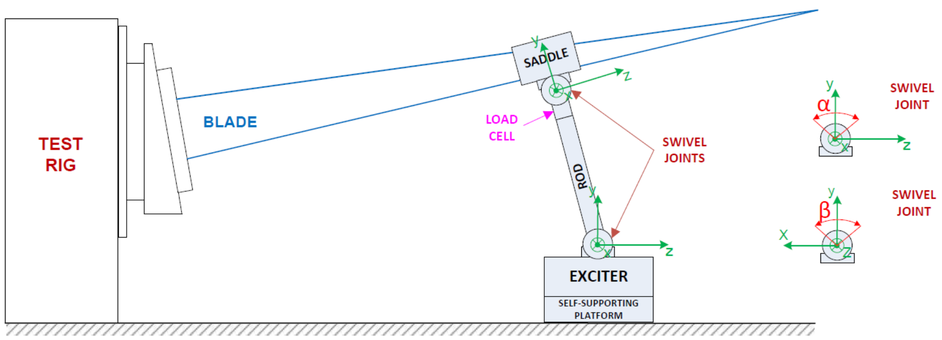


**Figura 6** Sketch of the LOAD application line

A mechanical ***ARM*** is proposed between the exciter and the ROD in order to transform the torque from the electrical motor into a linear force. Other proven equivalent solutions are accepted.

The ROD set will be minimally comprised of:

- Length-adjustable rod.
- Swivels.
- Load cell.

The saddle in Figure 6 is out of the specified scope.

#### 2.3.3.1.- ADJUSTABLE ROD

- It will link the exciter with the blade and it will mainly transmit loads aligned with its longitudinal axis.
- It will be subjected to varying tensile and compresion loads.
- It will be located between the swivel joints and the load cell.
- The blade section where it will be applied the load generated by the exciter could be located in a wide range of blade positions and thus heights. The rod length has to be adjustable so as to cover next range of heights: **4000mm - 10000mm**. It is suggested to offer a rod made up of several links for simplicity, i.e., **1000mm** (to be confirmed during the design phase) long assemblable fixed parts, plus a specific length-adjustable and assemblable link so as to cover the actual physical real height required by a certain test.

#### 2.3.3.2.- SWIVEL JOINTS

- A "***Swivel Joint***" has to be placed at each rod end in order to allow the rod to pivot freely as represented by **α** and **β** angles in Figure 6.
- These joints should ensure a smooth force input to the blade.
- **α** and **β** angles account for blade movement during a FLAPWISE fatigue test cycling:

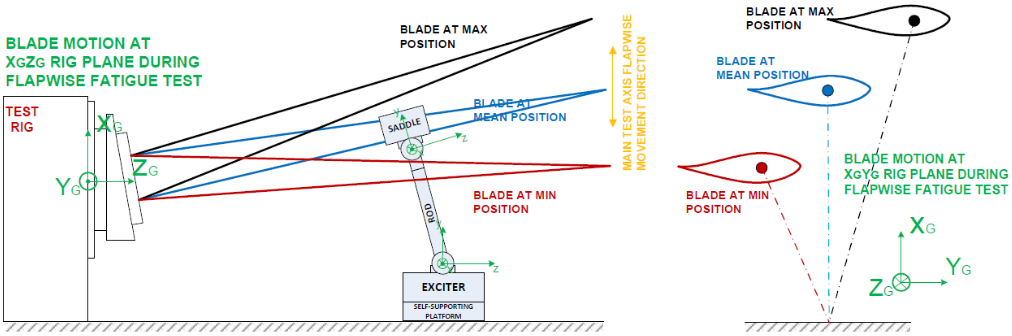


**Figura 7** Representation of extreme positions of the blade during FLAPWISE fatigue cycling

- The necessary **α** and **β** angles has to be specified not only taking into account the blade movement but also the type of exciter itself. From the point of view of the blade movement and as a minimum requirement, next free pivoting angles has to be offered:
    - α ≥±30º, plane YZ.
    - β ≤±5º, plane XY.

Motion centred on the y-axis.

**α=0** and **β=0** scenarios are defined in next figure:

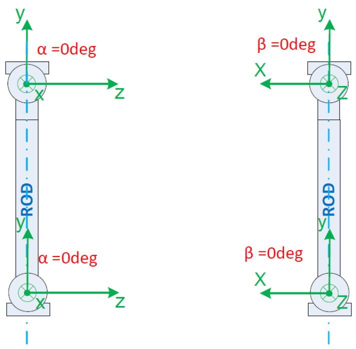


**Figura 8** Angle definition

### 2.3.3.3.- LOAD CELL

This is a critical sensor as it will measure the real load applied by the excitor to the blade.

- The rod will be equipped with a load cell sized to be capable of measuring the maximum applicable loads by the exciter.
- The load cell will be located between the rod and the top swivel in contact with the saddle.
- This signal will be monitored by both the control system and the DAQ (=Digital Acquisition System) of the test.
- Although it is not compulsory, it is suggested to include a double bridge load cell which will provide redundancy in terms of load signals, that is, one load signal would be the redundant measurement of the other and viceversa.
- The load cell shall be calibrated in accordance with ISO/IEC 17025 or equivalent. In case the load cell cannot independently calibrated, related specifications shall be traceable.
- CENER will check and confirmed load cell compatibility with its own DAQ electronics.

## 2.3.4.- FEATURES AND FUNCTIONALITIES

- The exciter has to comply to every operating load cases specify at Tabla 1. This means that FORCE, STROKE and FREQUENCY parameters have to be easily configurable.
- FORCE capabilities at Tabla 1 are set from a standstill condition, that is, the assumption is that the exciter does not apply any MEAN load in operation and thus, sinusoidal loading applied by the exciter is centered at 0kN.
- It is accepted that the own weight of the exciter ads a gravitational mean load to the blade's test setup.
- The exciter itself together with self-supporting platform, swivel joints, rod and load cell will be exposed to fatigue loading and in this regard, all these parts have to be designed "fatigue resistant" for a minimum of:
  - 10 milion cycles at máximum dynamic loading for moving parts.
  - 20 milion cycles at máximum dynamic loading for static parts.
- Dimensioning and strengh analysis records of any main part of the exciter set have to be available for any clarification that may come into alight during the tendering process.
- Special attention shall be paid to the fact that the ground based exciter unit will perform blade fatigue tests at resonance where during sinusoidal loading force and velocity parameters of excitation are in phase.
- Perfomance characteristics curves shall be delivered:
  - Specifically the máximum applicable peak forcé amplitude as a function of blade displacement amplitudes and for different test-frequency values.
  - Performance energy curves, specifically the máximum energy per sinusoidal cycle that can provide the exciter as a function of the test-frequency and for different blade displacement amplitudes.

  All these curves shall be represented for zero-mean sinusoidal loading at resonance, where force and velocity parameters are in phase.
- The capability of the exciter to apply a non-zero mean sinusoidal loading shall be an asset. If this is feasible, the offer shall explain its perfomance.
- It has to be assured smooth transitions when the exciter changes the direction of excitation during sinusoidal loading and thus, gearbox backlash cannot be accepted.
- The exciter set shall be designed in such a way that non-desired loads or vibrations are minimized.
- The accuracy of the applied FORCE to the blade shall be at least within **±5%** of the command load by the control system.
- The accuracy of the applied STROKE deflection to the blade shall be within **±2%** of the command displacement by the control system.

- The accuracy of the applied test FREQUENCY shall be within **±2%** of the command frequency by the control system.
- The control system must be able of finding the blade resonance frequency and tracking the resonance state during the test. See Section 2.4.- for more detailed information.
- The exciter set has to have a system in place that allows easy handling and lifting maneuvres.
- The exciter actuator must be of a kind that enters mechanical 'free wheeling' in the case of emergency shut down or power shortage. That is to say, worm gear excitation system is not accepted, since this kind of gear is only able to rotate by input shat side actuation, and will block the exciter movement abruptly in aforementioned scenarios.

### 2.3.5.- TRANSDUCERS

- The excitor shall be equipped with a sensor that provides direct or indirect measurement of the blade displacement at the blade section where the exciter is acting on.
- CENER will provide the sensors measuring the state of the blade under testing, such us acelerometers and/or straing gauges. As these sensors are mainly used for controlling purposes, the excitor need to be suited for any of them.
- The output signal coming from all the exciter related transducers such as load cell, blade displacement, accelerometers and strain gauges will be monitored in both the control system and the DAQ of the test. It is required a system that permits the doubling of signals without suffering from any signal quality loss.
- CENER will check and confirmed any transducer related signal compatibility with its own DAQ electronics.

### 2.3.6.- FUTURE EXPANSION CAPABILITIES

The "Ground Based Exciter" for Single Point Single Axis FLAPWISE Fatigue Tests has to be an expandable excitation system, up to the extent that with well-defined extensions is convertible into an excitation system capable of performing a wider range of tests in terms of test-configuration:

- Single Point Single Axis EDGEWISE Fatigue Tests.
- Multipoint Single Axis FLAPWISE or EDGEWISE Fatigue Tests.

Furthermore, the possibility of being able to upgrade it to Biaxial Fatigue Tests, FLAPWISE and EDGEWISE directions at the same time, will be positively assessed.

That is, a solution open to future extensions and upgrades has to be offered. Next figures show the aimed future feasible configurations:

- **Configuration No.1** → *Single Point Single Axis EDGEWISE Fatigue Tests*

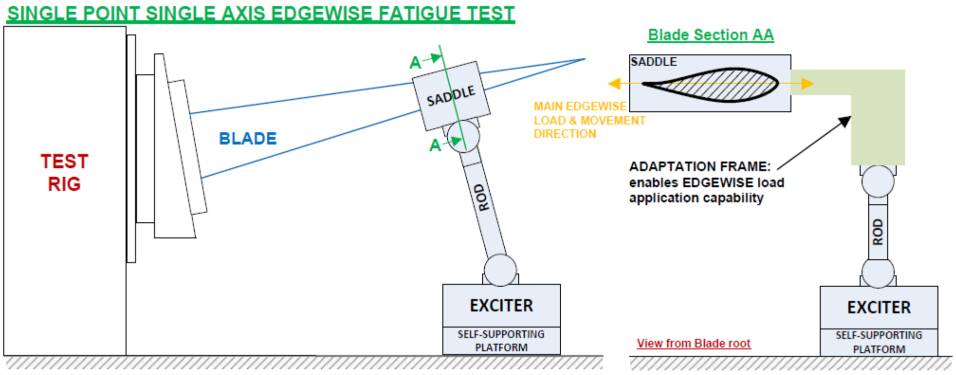


**Figura 9** Sketch of Single Axis EDGEWISE Excitation

- An "ADAPTATION FRAME" (=AF) shall be feasible so as to enable EDGEWISE load application capability.
- The AF should be offered as an optional item of the main supply.
- Figura 9 above represents the AF as a black box, as the idea is to leave room to any proposal that allows the use of the "Ground Based Exciter" also to carry out Fatigue Tests in EDGEWISE direction.
- The AF will have to be supported on the ground, either with its own self supporting structure or through the platform delivered with the main supply.
- EDGEWISE load application capability involves having to design a proposal that avoids slippage and overturning of the exciter.
- Controllability is of utmost importance. Same features and functionabilities as per defined at Section 2.4.-shall apply.

- **Configuration No.2** → *Multipoint Single Axis FLAPWISE or EDGEWISE Fatigue Tests*

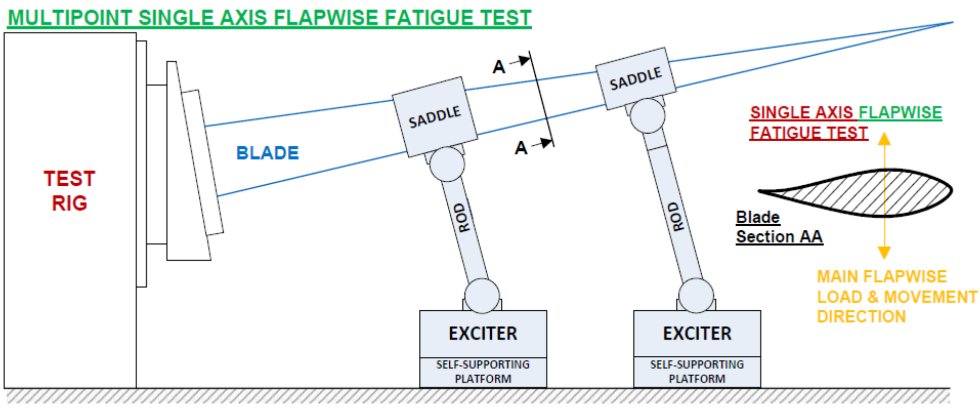


**Figura 10** Sketch of Multipoint Single Axis FLAPWISE Excitation

- The sketch for a Multipoint Single Axis EDGEWISE Fatigue Test will be similar but replacing "Ground Based Exciters" for FLAPWISE direction by exciters configured according to sketch shown in Figura 9.
- Load application process must be syncronised between both exciters whatever the testing direction is.
- Controllability is of utmost importance. Same features and functionabilities as per defined at Section 2.4.- shall apply.

- **Configuration No.**3 → *Biaxial Fatigue Tests*

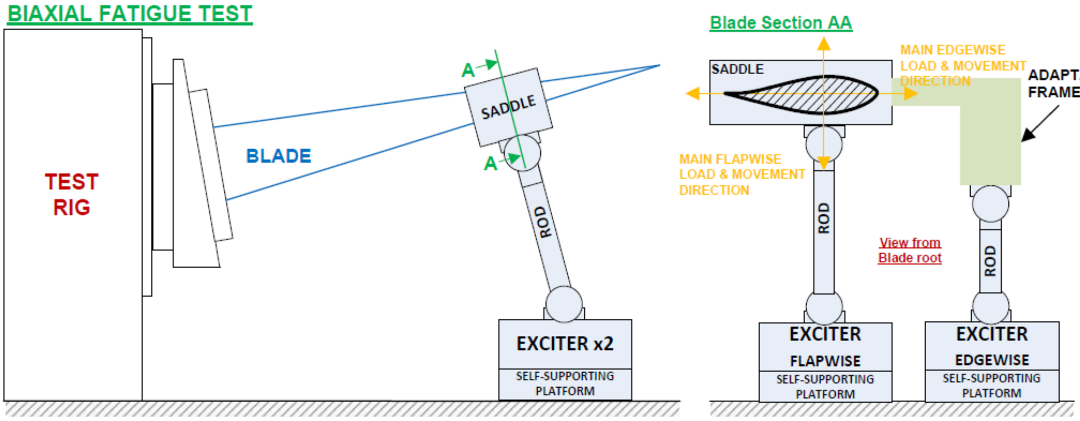


**Figura 11** Sketch of a BIAXIAL Fatigue Test

- Any layout that permits biaxial load application could be offered.
- Figura 11 shows biaxial load application over the same blade section. Another configuration that should be available is when each of the exciter acts on a different blade section.
- Load application process must be syncronised between both exciters.
- Controllability is of utmost importance. Same features and functionabilities as per defined at Section 2.4.-shall apply.

## 2.4.- CONTROL SYSTEM

### 2.4.1.- AIM

It is thought of a ***Feedback Control System*** where the controller monitors variables of the process and compares them with a reference, driving the system to a desired state while minimizing any delay, overshoot or error and ensuring a level of control stability and optimality. Focusing on Blade Fatigue Testing, the control system must be capable of applying an harmonic load of a given amplitude a certain number of cycles at the frequency, or very close to it, of the first mode of the system under testing.

### 2.4.2.- HARDWARE

- #### 2.4.2.1.- CONTROL LOOPS

It is suggested a type of "*Nested Control Structure*", where the exciter is controlled by 2 main nested control loops, that is to say, an inner loop and an outer loop. A system like this enables next list of control combination possibilities as a function of the feedback signal used in each loop:

| COMBINATION No. | INNER LOOP Signal | OUTER LOOP Signal |
|---|---|---|
| 1 | Force | Acceleration |
| 2 | Force | Strain gauge |
| 3 | Force | Displacement |
| 4 | Displacement | Aceleration |
| 5 | Displacement | Strain gauge |

**LEGEND**

Force = applied force by the exciter, signal provided by the load cell.

Displacement = blade section displacement at excitors actuation point, signal provided by the exciter.

Acceleration = blade acceleration of a certain reference blade section, usually located at blade tip.

Strain gauge = specifically bonded for control purposes at a blade section of high strains.

**Tabla 2** Feasible Control Loop Configurations

In either case, the outer loop commands the inner so as to regulate the excitation level with the aim of mantaining the signal level coming from the outer loop constant throughout the entire fatigue test. A system like this has also to allow to control only with the inner loop, where the safest option is to use the "Force" signal coming from de load cell.

In parallel, another additional controller should be available so as to manage the frequency of the test. This controller would be in charge of achieving and maintaining a certain phase angle between excitation, e.g., "Force" and blade behaviour, e.g., "Blade Strain". Exciting at resonance when testing gives typical phase angles around 90º.

<u>However, it could be also admitted any alternative control philosophy/architecture that permits test controllability in a manner analogous to that explained above, and as it is required in next Subsection 2.4.2.2</u>.

- **2.4.2.2.- REQUIREMENTS FOR THE CONTROL SYSTEM**

Specific required features to be fullfilled by the control system whatever the solution is offered:

- The control system must regulate the main parameters of the exciter, that is, applied forcé/displacement and/or test frequency. This system will enable to control the exciter according to required specifications.
- Searching and tracking of resonance is necessary during automatic operation. Environmental conditions cause the resonance to shift and the control system must be able of bringing the system back into resonance automatically.
- Searching and tracking of a certain test frequency at a specified phase offset from the resonance is also a required feature for automatic operation.
- It has to be able of changing the control command at any time and in a smooth and gradual way, either manually or in a programmed automatic way.
- The control system shall permit configuring limits and/or triggers over exciter related parameters and/or signals, and also over any signal wired to any of its AI or DIO cards. These limits and triggers must be able to be changed in real time without having to stop the running test.
- The controller must be able of generating warnings, alarms and emergencies as a consequence of having been exceed any of the configurated limits/triggers, and thus be able of executing the corresponding action for the safety of the blade and the whole excitation system.
- If the excitation system fails, it will generate a digital output signal that will be available at DIO card of the controller.
- The system must allow to stop the test at any time. This stop must be able to be executed manually or it can be an automatic stop as a consequence of exceeding certain prescribed limits/triggers of any signal coming from:
    - Exciter related parameters and/or signals:
        - Load cell.
        - Displacement.
        - System safety related variables.
    - Blade displacement and/or acceleration.
    - Strain gauges.
- The start up and stop transient of the fatigue test must be smooth and gradual until the stationary set point state is reached.
- Analog Input (=AI) channels: at least 16 channels will be available for signals coming from different sensors. Part of these channels will be used for control purposes, safety and for the aim of detection of alarms.
- Analog Output (=AO) channels: at least 8 channels will be available so as to duplicate for the DAQ those analog input signals monitored by the control system that are necessary for tracking the test.
- Digital Input/Output (=DIO) channels: at least 16 DI and 16 DO will be available for control purposes, safety and for alarm detection.

- Both AO and DIO channels will be mainly used for the interconnection of the control system and the DAQ.
- BUS communication could also be used instead of analog communication.
- Either analog and/or BUS communication is offered, CENER will check and confirmed the compatibility with its own DAQ electronics.
- The offer shall include all the necessary digital controllers so as to enable and make it happen all the aforementioned features and functionalities. Additionaly, next list of requirements shall also be satisfied:
  - Digital control in real time with alarm and trigger monitoring and control.
  - Controllers must allow flexible configuration.
  - Controllers must be easily configurated.
  - Remote control need to be available. The "Ground Based Exciter" **SET** as specified in Figura 4 will be foreseeable located at the testing hall with the exception of the PC running the whole system, which will be located at the control room.
  - The hardware shall incorporate signal conditioning for control purposes.
  - Possibility of implementing other type of tests using commands of different type such as: periodic, dynamic, ramps, block tests, test sequencers, function generators, possibility of reproduction of the content of external files and of any periodic or random signal recorded in the time domain.
- The control system must be expandable up to 4 control channels. It has to be delivered fully equipped so as to be able of controlling one exciter, but it must also be prepared for future extensions with the idea that it can control up to 4 actuators at the same time, either synchronously in the same test or as if they were independent tests.

### 2.4.3.- EMERGENCY STOPS

The system must permit management of two different type of stops:

- Controlled stops:
  - Smooth and gradual stops until the stationary standstill state is reached.
  - This process must be able to be activated both manually or automatically, where in this latest case, it would be activated as a consequence of exceeding a certain prescribed limit(s) and/or trigger(s).
- Emergency stops:
  - They shall act to avoid damaging shear forces on the tested blade.
  - Sudden stops that must immediately disable the exciter action without affecting the blade under testing. By any means, an emergency stop cannot infer any damage to the specimen under testing.
  - Once an emergency stop is activated, the exciter action shall be completely disable from the blade and the máximum admitted transient peak is:
    - Instant < **200ms**: no overloads greater than **Target FORCE+10kN** shall be transmitted to the blade.

- Instant > **200ms:** no overloads greater than **10kN** shall be transmitted to the blade.

It is understood that given values are difficult to prove in advance and thus, during commissioning applied loads have to be measure and in case is necessary, mitigate them to values below admitted transient peaks.

- This stop must be able to be activated both, manually acting on emergency push buttons, or automatically, where it would be activated as a consequence of exceeding a certain prescribed limit(s) and/or trigger(s).
- For the emergency manual stops, at least 5 emergency push buttons shall be provided which will be located one in the control room (Nº1), another button close to the control system (Nº2) and the rest along the blade testing hall (Nº3-5), being all located in easy access locations, see ANNEX 3.2.- that shows a drawing with approximate estimated locations for these push buttons.

In addition, the system shall incorporate the control elements relating to the physical safety of the system in the event of catastrophic failure of the blade under testing.

### 2.4.4.- SOFTWARE

In order to face any fatigue test campaign and with the help of this software, firstly the reference perfomance of the blade will have to be experimentally determined, in other words, the level of blade acceleration/strain/displacement directly related to the target bending moment curve of reference. Then, the system resonance frequency in the test direction has to be identified, which will be related to the real test frequency. At this point, main parameters of the exciter are to be adjusted until a good experimental bending moment curve distribution is obtained, and at this exact moment, peak and valley values of the outer loop feedback signal have to be recorded. These recorded values will constitute afterwards the control reference signals for the outer loop during the test. In parallel and in advance of the actual test, main driving parameters of the control system have to be adjusted so as to achieve an optimal perfomance during continous test execution.

In general terms, the software must provide a user-friendly interface with all the features and functionalities specified for the hardware of the control system, see Section 2.4.2.-. Moreover, it has to provide an easy access and configuration to all parameters directly involved in the blade fatigue test.

In short, needed technical features for the user interface could be gathered as follows:

- Flexibility and ease of use in order to define, parameterise, execute, monitor and watch any test in a simple way.
- Well documented software with interactive user help.
- Software that allows tailor-made action over: controllers, exciters, sensors, control signals, steps, limits and control strategies.

As a general rule, whatever the type of control system is offered, the related software has to be adapted to perform blade fatigue tests as per state in above sections of this document.

## 2.5.- POWER SUPPLY

CENER will be in charge of providing the necessary electrical power supply in order to run the whole system. CENER has estimated a minimum power supply of **200kW** so as to run the excitor along with any auxiliary system related to it. The selected supplier must confirm the power supply that needs to be installed to electrically feed its excitation system.

The selected supplier must provide a list of materials and sufficient diagrams to carry out the electrical installations necessary for the operation of the equipment.

## 2.6.- OTHER SPECIFICATIONS

### 2.6.1.- HANDLING AND LIFTING

- Subcomponents of the “Ground Based Exciter” **SET** must be designed for being lifted by a 40 tones gantry crane and thus, none of them shall exceed crane’s load limit.
- Dead masses for the self supporting platform must be designed for being lifted either by a crane or by a fork lift.
- Lifting inserts shall be included on the platform in order to enable the use of rollers for moving the whole SET.

### 2.6.2.- OPERATIONAL CONDITIONS

- Exciter SET must be usable indoor from -10ºC to 40ºC.
- It will be stored indoor.
- Outdoor usability shall be offered as an optional of the main supply.
- Corrosion protected ítems are required for the outdoor optional.
- Every main ítem will be delivered painted and it has to be declared with what RAL.
- Noise level should be as low as possible when the exciter is running. An orientative noise level shall be given, and in what operational condition takes place shall be defined.

# 3.- ANNEXES

## 3.1.- ANNEX 1: DRAWINGS OF THE BLADE TESTING LABORATORY

### *TOP VIEW*

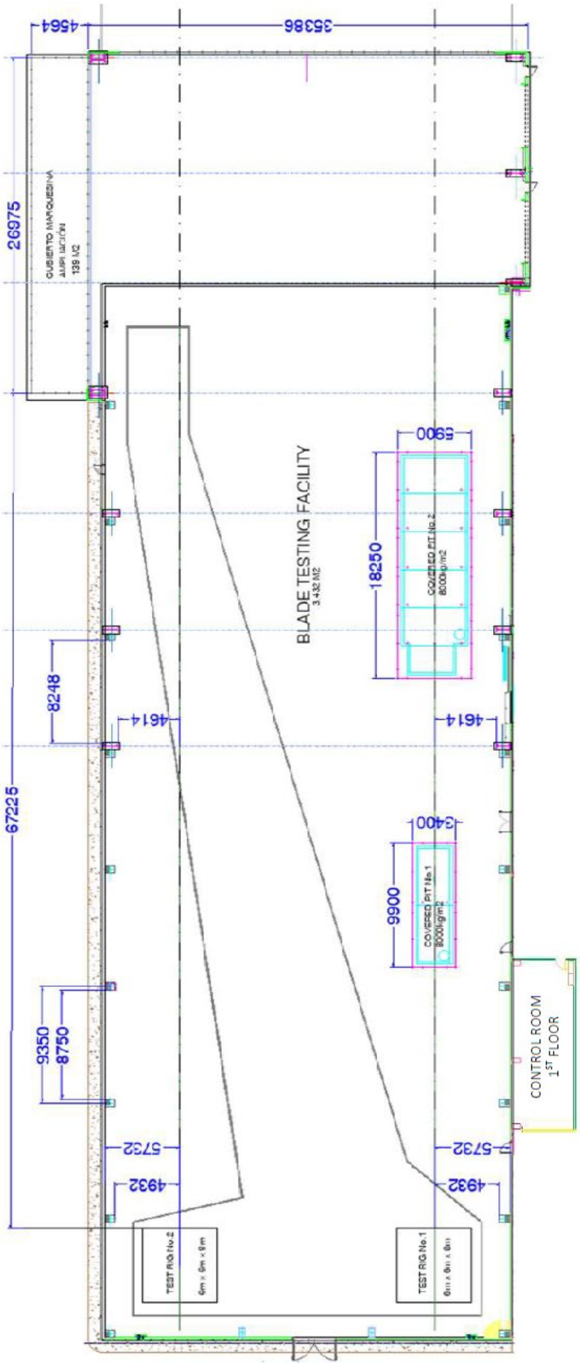


**Figura 12** TOP view of the Blade Testing Hall

Note: all dimensions in “mm” unless otherwise specified.

### *ELEVATION VIEW*

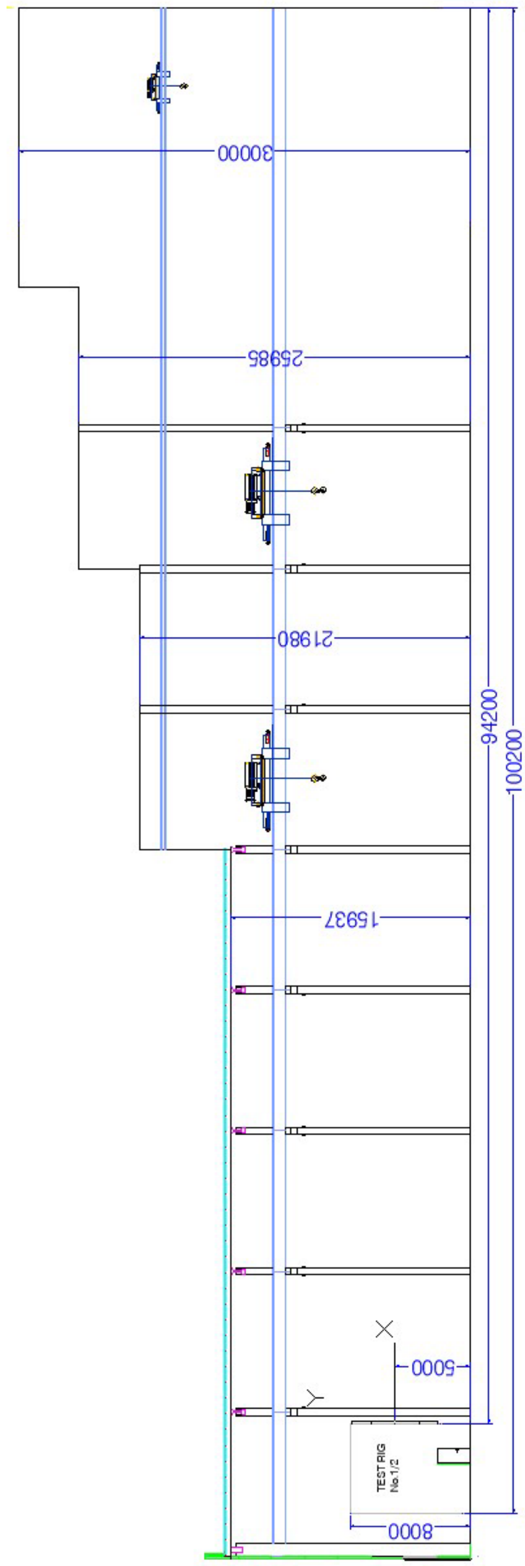


**Figura 13** ELEVATION view of the Blade Testing Hall
Note: all dimensions in “mm” unless otherwise specified.

### 3.2.- ANNEX 2: EMERGENCY PUSH BUTTONS LOCATION

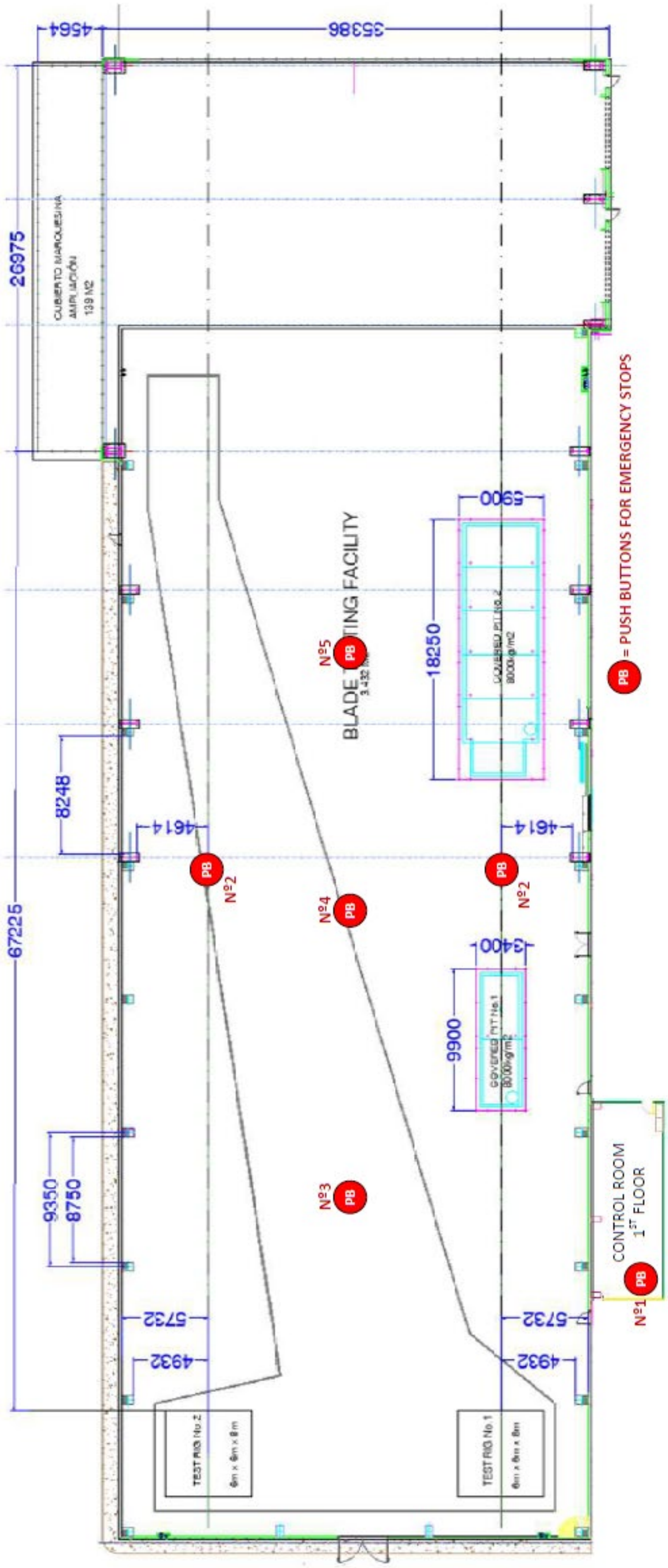


**Figura 14** Lay-out for EMERGENCY push buttons
**Figura 15**