Athermic Gimbals / Cardan Tip-Tilt Mount for Low Temperature and Vacuum Conditions with Clamping Possibility

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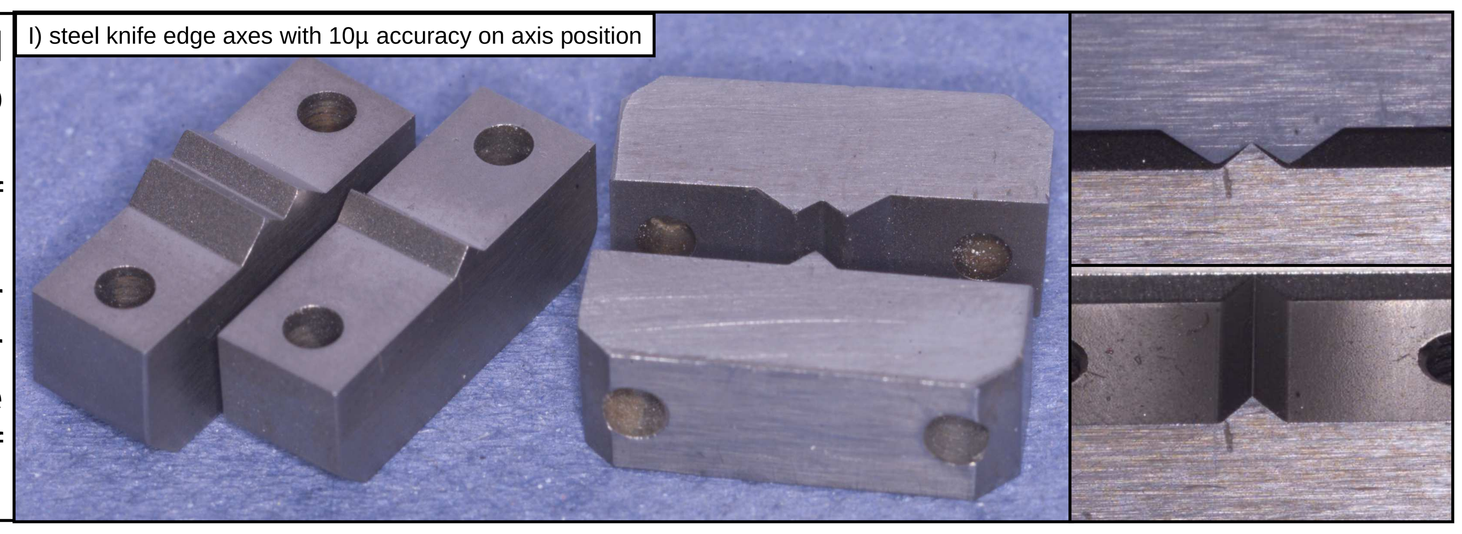
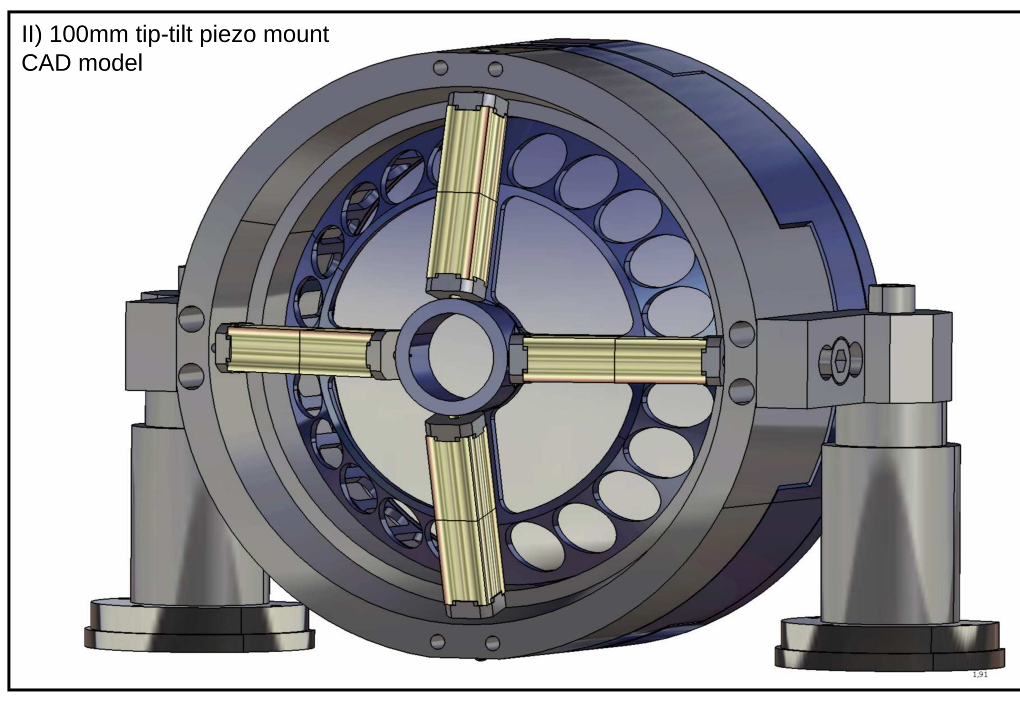
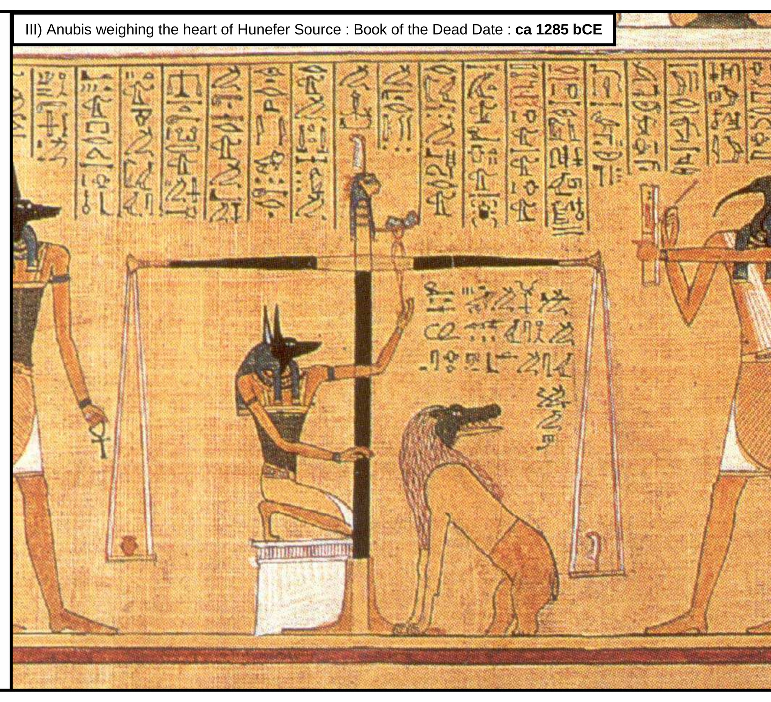
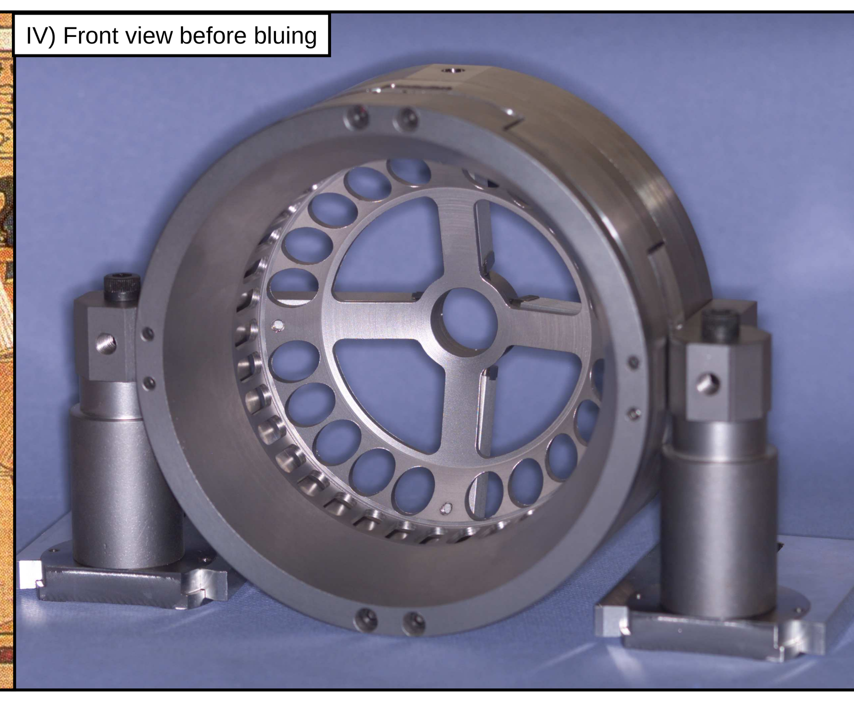
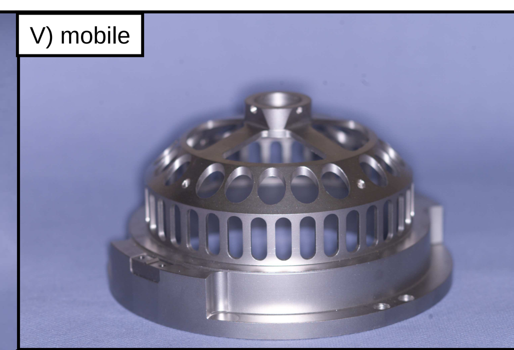
Abstract: New generation optical instrument for astronomy will use tip-tilt system to correct the first orders of optical perturbation. As scientific interests imply to observe in the 1µm to 5µm wavelength band, with high signal-noise ratio because of the low level of scientific objects, new generation instrument will also need a cold pupil.
Thus the use of tip tilt systems as cold pupils in cryostat will be an improvement for the next generation of instrumentation as EAGLE (E-ELT) for instance.
The concept presented is a classical gimbals tip-tilt mount for mirror that do not use reaming for axis definition nor flexible matreial, so it is usable in vacuum condition and/or at low temperature because it neither uses lubricant nor sliding faces. This design is gravity independent and can be moved by piezos, voice-coils or magnetic actuators. The overall design of cardan easily permits to deal with thermals issues and makes the system defocus free. The use of non-flexible axis allows using outside clamping to make the transportation safe.

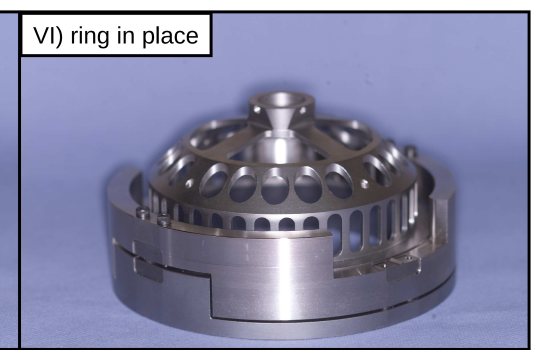

I) steel knife edge axes with 10µ accuracy on axis position

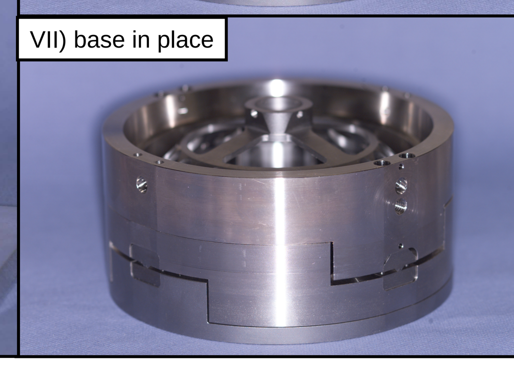

II) 100mm tip-tilt piezo mount CAD model

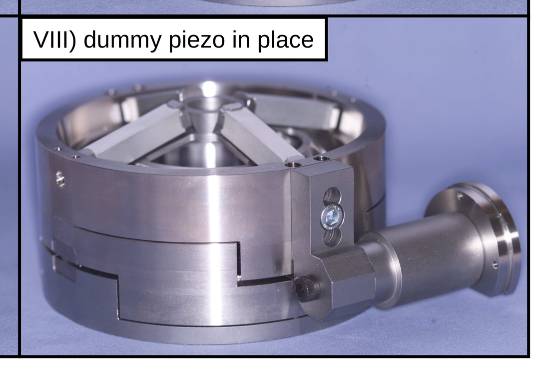

III) Anubis weighing the heart of Hunefer Source : Book of the Dead Date : ca 1285 bCE

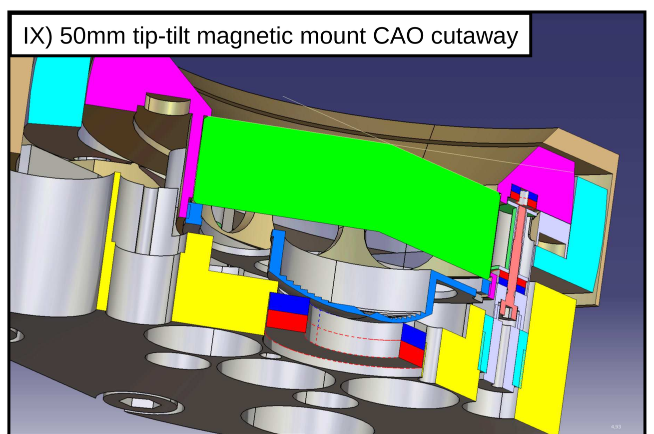

IV) Front view before bluing

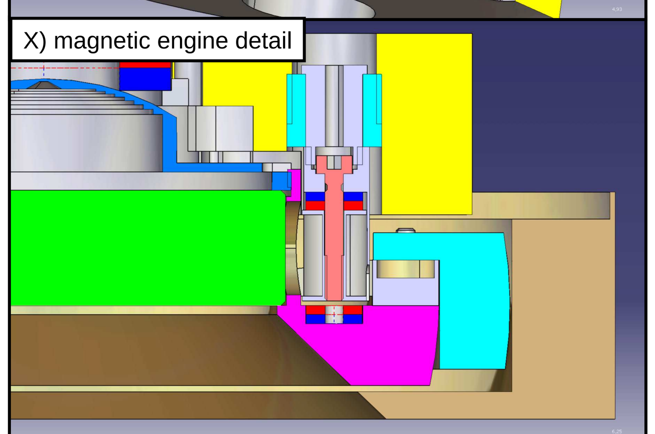

V) mobile

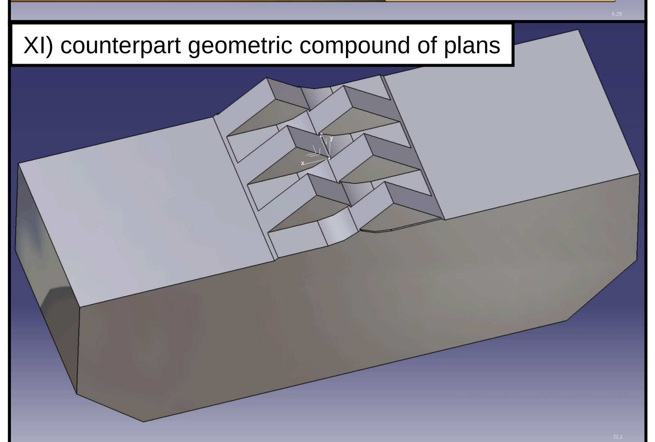

VI) ring in place

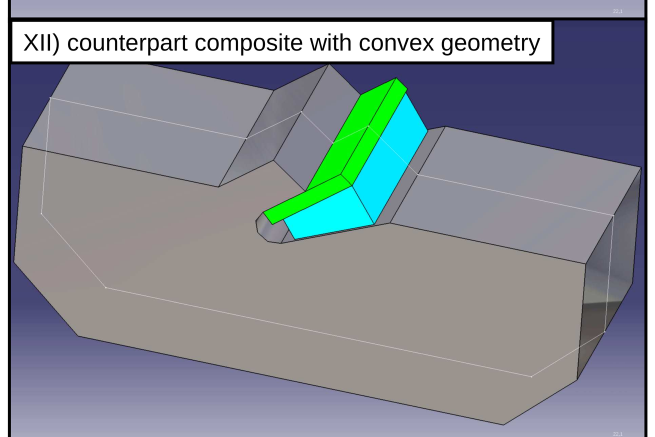

VII) base in place

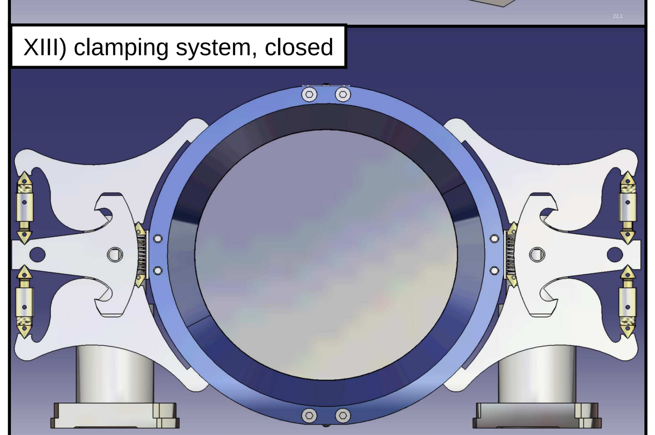

VIII) dummy piezo in place

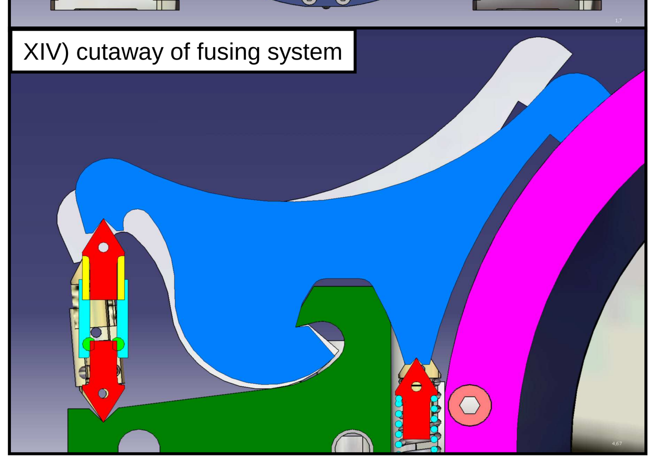

IX) 50mm tip-tilt magnetic mount CAO cutaway


X) magnetic engine detail


XI) counterpart geometric compound of plans


XII) counterpart composite with convex geometry


XIII) clamping system, closed


XIV) cutaway of fusing system

Technical context: the need covers three points: optic, vacuum and cryogenic plus one hidden point: control command.

Optical performance: tip-tilt are used to provide a stable and fixed pupil to instrument without introducing aberration as defocus. To manage this problem, usual solution is to cross axis of rotation on the center of the mirror, S, by a cardan mount. Even if tip-tilt is a mobile part, unplug position have to be reasonably rigid and neutral so tip-tilt have to be gravity independent.
Vacuum performance: using under vacuum forbids some materials for design like porous, aqueous or solvent-based materials. It forbids gliding systems on "dry" larges surfaces if materials in contact are too close in strength or in nature. It forbids traps like deep holes or large flats surfaces in contact if pump efficiency is low or UHV required.
Cryogenic performance: cryogenic environment is an issue but it can be a chance if temperature is low enough to use supra conductor materials for electrical motion… Mechanical design has to manage the down of temperature by choosing materials that have similar thermal expansion. If cryogenic power is limited, mass have to be reduced as low as possible and materials have to transfer energy as fast as possible.
Control command performance: mechanical must be infinitely rigid, inertia as low as possible without stick-gliss or rubbing. Typical need is 100Hz bandwidth with a 1 kHz sampling loop.

Discussion of Choices and solutions :
For demonstrators, optical glass mirrors that exist in high quality had been chosen, one Ø100mm for piezo demonstrator and one Ø50mm for magnetic demonstrator.
These mirrors are quite heavy (up to 260gr for the Ø100mm one) and control command need inertia and gravity center, G, on the cross of both axis, S, so every moving part or sub-assembly must have G centered on this crossing, S, and inertia matrix zeroed on diagonal. That means every sub-assembly has to be equilibrated on the center of the mirror: S.
Cardan mount is composed of three sub-assemblies, the "mobile" sub-assembly that contain the mirror and that is driven by actuators. The "ring" that provide two crossed axis and the "base" that give mechanical rest for the first axis of the ring and the fixed base of actuators.

Mobile issue: (V)
Mechanical: In order to equilibrate the mobile, a mass, m, has to be put in the front of the mirror but, to reduce inertia, the gravity center of this mass, Gm, has to be as close as possible to S. This point allows to choose the material of the mobile main part in high density materials like tungsten, molybdenum, silver, gold, brass, copper, lead, uranium or steel…
Cryogenic needs good thermal conductivity so exit steel, tungsten and molybdenum.
Vacuum needs no traps so exit tungsten and molybdenum that is commonly fritted material, lead and uranium are exit too for vapor problems.
Optical needs rigid support and same thermal expansion as mirror, so exit again silver, copper, gold, lead, uranium and silver.
Mobile solution: the winner is steel for large mirror; brass could be used for small mirrors… strength is good for light weighting the mount on mirror side and density is high enough to have a counterweight side close to G. Thermal expansion of steel can be made the same as that of glass mirror allowing gluing. For brass mobile, mirror has to be conventionally mounted.

Ring issue: (VI)
Mechanical: No problem to equilibrate the ring, the main issue is to reduce the inertia as low as possible while keeping it very rigid in order to limit focus resonance. So the material has to be rigid and overall design without opened cells if light weighted. Materials as steel, beryllium alloys, magnesium alloys, ceramics, SiC or carbon composites could be used.
Cryogenic needs: issues are multiple. The thermal conductivity to down the temp passes through axes or through copper tress that could be a fault for control command and inertia. The thermal expansion on optical axis has to be null. The thermal expansion on X, Y axis has to be the same as that of mobile and base in order to avoid stress in axes.
Vacuum needs: same as mobile.
Optical needs: the ring will not introduce defocusing
Ring solution: same material as mobile and base, with symmetric design centered on the crossing of axis.

Base issue: (VII)
Mechanical: connecting to the ground the first axis and the fix part of engines for motion. Providing neutral position of mirror in unplug mode and flatten assembly on the axes
Cryogenic needs: the thermal expansion on X axis has to be the same as that of the ring in order to avoid stress in axes.
Vacuum needs: same as mobile.
Optical needs: The thermal expansion on optical axis, Z, has to be null
Base solution: positioning fixture on the X axis and using the same material as that of the ring. Positioning actuators in push-pull pair, to push mobile and ring on axes ***(IX-X)*** with angle ***(VIII)***

Axes issue: (I)
Mechanical: low torque (RX), high strength (TX, TY, TZ),
Cryogenic needs: good thermal conductivity, low temp usable so no flexible materials Flexible material that would alter reliability…
Vacuum needs: no traps, no sliding surfaces, no oil or grease
Optical needs: rigid in Z direction.
Axes solution: the solution is to use same axes as found in roman' scales ***(III)*** for thousands years: knife edge.
Optically: the mechanical axis is real and well defined (which is not the case with rotating shaft nor with flexible pivots like Bendix).
Vacuumly: closed area is kept as minimal as possible, no oil or grease are needed.
Cryogenicly: thermal conductivity is not good by the low contact area but cooling optical glass mirror has to be stress-less…
Mechanically: this knife edge pivot looks is very simple to machine, even in high strength material like diamond or CBN (cubic boron nitride). The problem takes place in the counter part of the knife: the knife edge could be sharp up to mono atomic razor blade because it is convex geometry but counter part has to provide line contact. The counter part can be plan or concave geometry; if plan, the real axis exists but his position is not well defined; if concave, sharpening is difficult to achieve. A solution could be composite counter part made with convex geometry assembly ***(XII)*** or geometric compound of plans ***(XI)***.

Clamping: (XIII, XIV) the ability to lock the mechanism is useful for alleviating axes during transportation and axes no longer need to be sized by that point of view. Clamping can provide thermal drain directly on the moving part when temp down. For an astronomical instrument, clamping has to be reusable, but for single use, fused system can be used to release mechanism moved by a spring. Here is shown single use clamping system using knife edge axes. Electrical power between cyan and red parts will fuse green annulus of fusing material. The yellow part is made of ceramic. Blue part can be nonconductive and spring warmed by same way.