

INNOVATIVE CONNECTING ROD FOR HIGH PERFORMANCE ENGINES

Preliminary note

The present exercise has been inspired by a case study related to an activity carried out by Gaetano Cascini and Francesco Saverio Frillici in favour of SCAM srl (Italy) during the summer of 2006. Some details have been therefore omitted.

Introduction

A connecting rod for 4 strokes engines is basically constituted by three subsystems (fig. 1): the stem with a small “eye” at its narrowest end where the piston pin is inserted; the “hat”, a semi-circular part that, together with the wider end of the stem, constitutes the “big eye” where the connecting rod is mounted on the engine shaft; 2 screws that fix the hat on the stem.

A connecting rod is subjected to fatigue loads, due to alternating inertia loads and gas pressure in the combustion chamber. As a consequence, the screws must support a highly variable normal stress and in high performance engines (e.g. Formula 1) constitute one of the weakest points of the overall system.

During the last decade relevant improvements have been obtained thanks to special steel and titanium alloys tailored to support fatigue loads with high strength and low fragility. Within this trend, a niche market of special steel screws for extreme loading conditions has grown and 2-3 main producers share the world market. As a consequence these companies can arbitrarily define the price of the screws.

A small competitive firm producing shafts and connecting rods for race engines is clearly not able to sign exclusive supply agreements with the above mentioned screw producers, because of reduced production volumes. Besides, the biggest competitors have higher chances to sign exclusive supply agreements. As a consequence there's the necessity to radically change the structure of a connecting rod.

It is worth to mention that due to external constraints it is not possible to build a one-piece connecting rod, by mounting it on a multi-parts shaft. It is also evident that, due to the special destination of the connecting rod, reducing weight is the most important requirement to be satisfied.

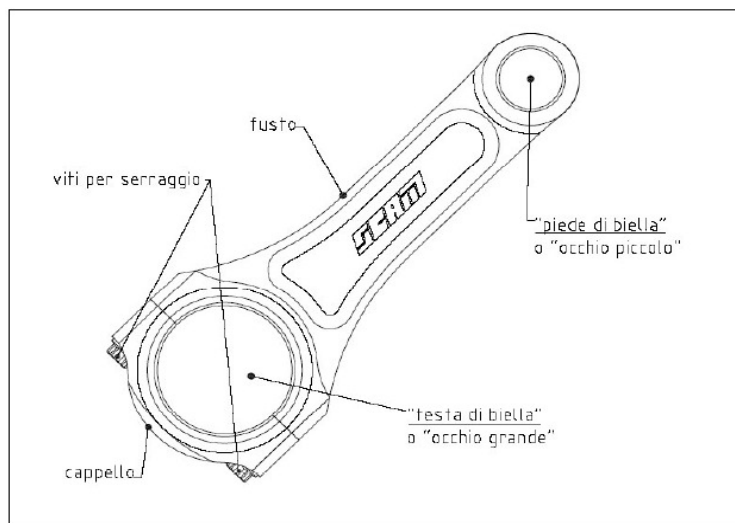


Fig. 1 – Connecting rod for 4 strokes engines.

Since the system is very simple, a functional analysis doesn't provide a clear view of the design choices behind each detail. Nevertheless, by taking into account the design parameters, several contradictions can be identified. Among them, a step by step ARIZ analysis has been performed to the following.

ARIZ-85C, step 1.1

- TC-1: if the connecting rod is equipped with small/light screws that join the stem and the hat of the connecting rod, then the screws are submitted to fatigue stress that overcome their maximal strength.
- TC-2: if the connecting rod is equipped with screws capable of supporting the fatigue loads acting on the connecting rod, then their weight exceeds the maximum acceptable value.

ARIZ-85C, step 1.2

The technical contradiction above involves the following conflicting pair:

- Tool: the screw(s)
- Product: the connecting rod

ARIZ-85C, step 1.3

In Fig. 2 conflicts TC-1 and TC-2 are depicted, by representing the excessive weight of the screws as an own harm, even if it should be better represented as an inertia overload (harm) on the overall system.

Screw

Connecting road

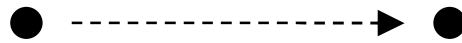


Fig. 2a – ARIZ-85C - Step 1.3: TC1

Screw

Connecting road

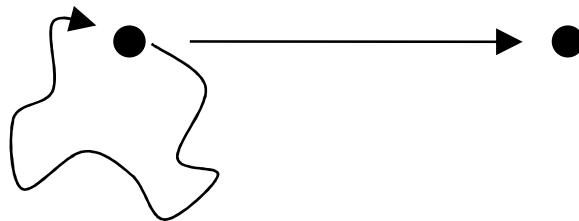


Fig. 2b – ARIZ-85C - Step 1.3: TC2

ARIZ-85C, step 1.4

TC-1 was chosen as the side of the contradiction to act on, since it is closer to ideality (no weight).

ARIZ-85C, step 1.5

Intensifying this conflict leads to the elimination of the screw: if the connecting rod is equipped with the lightest/smallest screw, i.e. no screw at all joining the stem with the hat, then the screws are not able to support any load.

ARIZ-85C, step 1.5

Thus, the problem model can be summarized as follows:

- the conflicting pair is constituted by the screw and the connecting rod;
- the absent screw doesn't add any weight to the system, but is not able to support any load;
- It is necessary to find an X-component/field/property, which would support the loads action the connection rod, without adding weight to the assembled connection rod itself.

ARIZ-85C, step 1.7

The above described problem can be preliminarily approached by means of the Inventive Standards.

Indeed, in the intensified form of the conflict, we have an incomplete S-F model with just a Substance (the connecting rod). Thus, Standard 1-1-1 should be applied.

Due to the nature itself of the system and the impossibility to radically change its structure, a Mechanical Field interaction should be kept.

Indeed, the opportunity to substitute the screws by fixing together hat and stem (e.g. welding, mating with interference) was properly considered, but finally discarded due to other system requirements.

ARIZ-85C, step 2.1

The operational zone where the conflict arises is constituted by the “big eye”, i.e. the portion of the connecting rod aimed at being connected with the engine shaft.

ARIZ-85C, step 2.2

The intervals when the connecting rod is subjected to traction loads ($T1'$), the time when it is subjected to compression loads ($T1''$) and the time when the connecting rod is mounted on the shaft ($T2$) constitute the operational time.

ARIZ-85C, step 2.3

The main internal resources can be identified:

- System resources: stem, hat, screws with their shapes, geometrical position/orientation, material etc;
- Subsystem resources: the small eye, head of the screw, thread of the screw;
- Supersystem resources: piston pin, piston, shaft.

ARIZ-85C, step 3.1

IFR-1: An X component, without complicating the system, and without causing harmful side effects (mainly exceed maximum weight) join together stem and hat of a connecting rod under traction ($T1'$) and compression ($T1''$) loads, by forming a stable closed eye to be connected to the engine shaft and preserves the connecting rod ability to transmit forces.

ARIZ-85C, step 3.2

Then, the Ideal Final Result can be consequently intensified, by avoiding the introduction of any new substance/field and applying as the X-component the resources identified at step 2.3, primarily the resources of the tool itself.

The IFR can be reformulated accordingly:

- the screw size/shape/position, without overcoming its admissible weight, join together stem and hat of a connecting rod under traction ($T1'$) and compression ($T1''$) loads, by forming a stable closed eye to be connected to the engine shaft and preserves the connecting rod ability to transmit forces;
- the stem/hat is shaped so to allow the adoption of light screw(s) capable of joining together stem and hat of a connecting rod under traction ($T1'$) and compression ($T1''$) loads, by forming a stable closed eye to be connected to the engine shaft and preserving the connecting rod ability to transmit forces;

ARIZ-85C, step 3.3

At macro level, the physical contradictions can be expressed by analyzing the preferred state/value of each physical parameter of the above listed resources.

Among the others, the following physical contradiction was selected:

- the screw during T1' and T1'' should be positioned orthogonal to the axis of the connecting rod in order to avoid to be submitted to fatigue loads and should be positioned parallel to the axis of the connecting rod in order to fix together the stem and the hat of the connecting rod and to transmit its forces properly.

ARIZ-85C, step 3.4

The physical contradiction at micro-level can be formulated as follows:

- during T1' and T1'' there should be force transmitting particles (in this case it is worth to consider the particles of a field, not just of a substance) so that a screw orthogonal to the axis of the connecting rod fix together the stem and the hat of the connecting rod and there should not be force transmitting particles so to avoid fatigue loads on the screw itself.

ARIZ-85C, step 3.5

The big eye of the connecting rod should contain force transmitting particles so that a screw orthogonal to its axis fix together the stem and the hat of the connecting rod itself without applying fatigue loads to the screw.

ARIZ-85C, step 3.6

The last formulation of the physical contradiction triggers a conceptual solution even without applying any inventive principle, just by translating the IFR-2 into a structure. The connecting rod is reshaped so that the mating surface of stem and hat becomes parallel to its axis; consequently, a screw orthogonal to its axis fix them together and due to its placement orthogonal to the force direction is not submitted to fatigue loads. Thus traditional steel alloys can be adopted even reducing the size of the screw itself.

The solution is almost depicted, but still a clearer definition of the way to transmit forces between the big eye and the small eye must be conceived.

With the aim of submitting the screw just to a static normal load, avoiding shear (both static and alternating!!) we have to introduce something new in the system.

A mechanical designer will quickly visualize numerous possible structures fulfilling this task. In our case the introduction of a hinge was proposed as depicted in fig. 3.

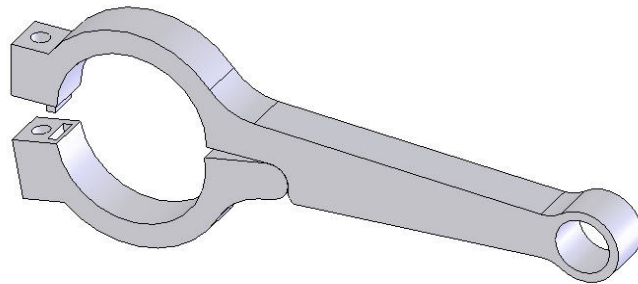


Fig. 3 – Initial solution: the screw fix the big eye of the connecting rod, but is not subjected to fatigue loads.

Indeed, the introduction of a new substance (the hinge) increases the complexity of the system.

In other words the hinge should be there, in order to assume the role of transmitting forces between the big eye and the rest of the connecting rod, but should not be there in order to reduce the complexity of the system.

With the same logic followed between steps 3.1 and 3.2, instead of introducing new substances, it is suggested to adopt available resources.

Among the available resources identified at step 2.3, the pin of the piston can be used as the

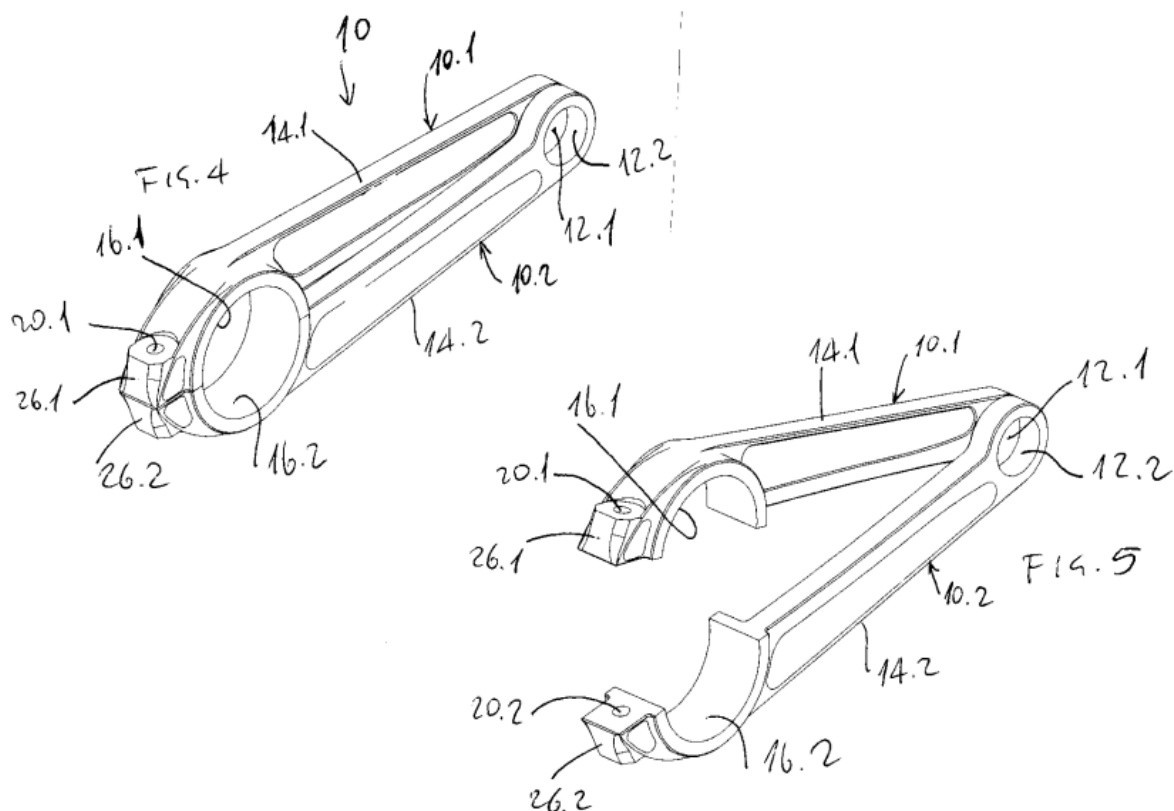


Fig. 4 – Solution evolved according to an increased use of available resources. The final connecting rod is 12% lighter than the original one and its screws are subjected to fundamentally static loads instead of alter-

Conclusions

The final solutions allowed the development of a new generation of connecting rods for race engines: with a lightly more complicated assembly process (indeed a negligible drawback in this specific field), a double relevant advantage was reached: the connecting rod is 12% lighter than the original one thanks to the reduced mass of the stem allocated to screw containment; moreover, traditional steel screw can be adopted instead of special alloys thanks to the absence of fatigue loads.