7.10.3.1 Fender's Stratocaster vibrato (aka tremolo)

On August 19, 1929 – when few people were thinking about electric guitars – Clayton Kauffman filed for a patent under the title *"apparatus for producing tremolo effects"* (US 1,839,395). According to it, a spring-loaded, movable tailpiece enabled the change in pitch, *"so as to produce a tremolo effect"*. Indeed, it was this "Doc" Kauffman who later was Leo Fender's business partner for a short time in the jointly operated K&F company, before Fender started his "Fender Electric Instrument Company" in 1946 [Duchossoir]. The latter's first electric guitar, the Esquire, successfully entered the market around 1952, and then had weathered the metamorphosis into the Telecaster. Time was right for the release of a further guitar: *"We didn't invent the tremolo thing. It had been used on many other instruments, but we wanted it because it seemed to be very saleable [Tavares]"*. On August 30, 1954, Leo Fender filed for a patent for the **Stratocaster** (US 2,741,146), an electric guitar with a *"synchronized tremolo"*. Duchossoir describes the first experiments: *"the first vibrato designed by Leo Fender was, by all accounts, fairly similar to the unit later installed on the Jazzmaster guitar released in June 1958. It allowed some string length between the bridge and the tailpiece, were the strings were anchored. This early version was fitted with individual roller bearings, meant to facilitate return to pitch, but in fact they were damping the string sustain because of too much lateral vibration. It would also appear that the steel rod used as a tailpiece did not anchor the strings firmly enough and their energy was dissipating to the detriment of tone and sustain."* Leo Fender comments: *"We had to chunk the whole thing and completely retool"*. And: *"With a string, you can't have vibration in any direction at the bridge, it's got to be as solid as the Rock of Gibraltar"*. This is stated by Leo Fender (bookkeeper by education), and darn is he on target. It's a different story that as late as 2005, the "experts" at Gitarre & Bass opine that *the largest part of the string vibration should be fed to the body.*

In order to keep bridge and tailpiece from developing too much of a life of their own, Fender combines both into a single unit supported on knife edges – that was the groundbreaking idea. Why he deviates again from it in the Jazzmaster remains Fender's secret. **Fig. 7.118** shows a cross-section through the Stratocaster vibrato. The strings run across adjustable bridge saddles to a so-called "sustain block" fitted with tension springs at its lower side that provide the counter-traction. The L-shaped base plate is held in place by 6 wood screws that are not fully bolted down such that the base plate can easily be tilted upwards. The rotational axis is located between wood screw and slightly countersunk hole in the base plate. The traction force Ψ generated by the strings (at the time about 730 N) causes a torque at the short lever (about 9 mm) that is compensated by 5 tension springs at the long lever (about 42 mm). Today, lighter strings are customary and often only 3 springs are used. Their exact traction force may be adjusted via two tension screws (not shown in the figure). The pronounced bend angle with which the strings run across the bridge saddles causes relatively high contact pressure forces, and any residual damping due to the short residual string section (Chapter 7.7.4.3) is weak. Nothing is perfect, now even this design, but it works well enough that to date Fender has only introduced small changes.

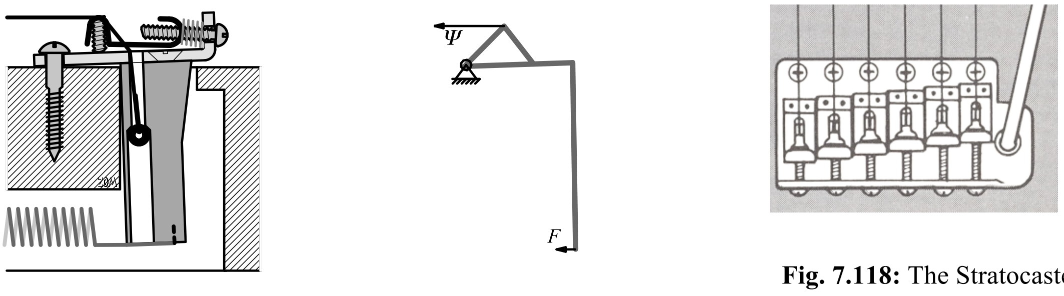

Fig. 7.118: The Stratocaster vibrato.

 Translated by Tilmann Zwicker

One of these changes concerned the mounting screws: how does a force distribute itself across 6 screws? In an undefined manner! And so the 6 mounting screws were reduced to two in 1987 for the American Standard Stratocaster, which resulted in a reasonably unambiguous knife-edge bearing, at last. The second change concerned the bridge saddles: originally shaped from sheet metal, they became die-cast cuboids in the 1970's. Not on all models, though: some were still produced with **sheet-metal bridge saddles**. Both versions do work – however, they have their special manufacturing tolerances. Depending on circumstances, every bridge saddle is one of a kind with the 3 screws at each end giving it highly individual contact-stiffnesses and -damping.

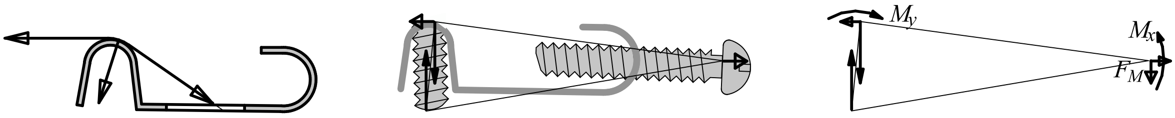

Fig. 7.119: Flux of force in the Stratocaster bridge.

The flux of force in a bridge saddle is shown in **Fig. 7.119**: the bent string exerts a force pointing downward to the left at an angle onto the bridge saddle (compare to Fig. 7.113). Since string diameter, and position and angle of the bridge saddle vary, the amount and the direction of this force vary, as well: its *x*-component can range from 5 to 35 N, its *y*-component from 21 to 73 N. The *y*-component is absorbed by the lower side of the vertical adjustment screw[1], and the *x*-component is absorbed by the horizontal tension screw. Since, however, the correspondingly parallel forces do not run through the same point, two torques will result – designated M_x and M_y here. As a rule, these torques will not be of the same magnitude which is why the small vertical force F_M needs to additionally act on the tension screws. Given the usual geometry, this force will be directed downward (in the figure) and finds its counterforce (not indicated) at the vertical adjustment screw. The larger F_M is, the more the horizontal tension screw braces itself into the thread of the bridge saddle, and the more this connection becomes solid. Thus: the smaller F_M is, more wobbly the arrangement. F_M becomes small if the string runs across the bridge saddle at a small bend angle. This is, at the same time, the scenario in which the other forces become small and in which only small relative movements – which would remove vibration energy from the string – are possible.

Now, the users of Strats are not exactly know for constantly complaining about un-playability and lack of sustain – for the majority of these guitars, the adjustability of the bridge saddles does not need to be exploited to the limit, and most bridge saddles offer a secure footing to the string. If the bridge saddle is moved back so far that the string experiences another bend at the oblong hole, adequate retention forces can be expected also for light strings. Problems can result only for guitars with such an unfavorable neck fitting that the bridge saddle needs to be positioned at the furthest front end (i.e. the beginning) of the tension screw. Still, when comparing this to the jiggle existing on the Jazzdesaster (Chapter 7.10.3.2), even F_x = 21 N could still be called rock-steady.

When dealing with a vibrato system, the main questions always are: how stable is the tuning, and how large is the possible detuning? In this respect, the Stratocaster vibrato offers an acceptable performance, with some potential for improvement. The effect of the vibrato is, however, not limited to the above main functions, and therefore we will in passing look at some **side-effects**: the tension spring located within the guitar body vibrate close to the bridge pickup and induce electrical voltages, and moreover the sustain block with all the springs constitutes a resonance system.

[1] Friction forces are disregarded for his simplified consideration.

6 steel strings are positioned above the bridge pickup of the Stratocaster, und 5 **steel springs** below it (today, often there may be merely 3 of them). Normally, the steel springs are concealed but that does not keep them from having an inductive effect – and one that is only bearable because they are further away from the pickup than the strings. Each of the springs can adopt longitudinal, transverse, and rotational vibrations, and will do so, too, as soon as strings and/or guitar body are set in motion. Apparently, this latent life of its own is not entirely undesirable but is seen as a kind of Strat-typical **reverb system** (although there are also guitars with the vibrato springs wrapped in a soft cloth to reduce just that effect). A reverb in the usual sense must, however, not be expected because this system features merely a few pronounced resonances. The investigated Strat-specimen (010-gage string set, 3 springs) showed a **47-Hz-resonance** that also prominently manifested itself as a line in the pickup spectrum. This is the Eigen-frequency (natural frequency) of the vibrato arrangement, composed of the stiffness of strings and springs, and (mainly) the mass of the steel block. Eigen-vibrations of the springs appear around **140 Hz**, and at harmonics thereof. The resilient string bearing makes itself felt as selective absorption in the bridge conductance at a frequency range around 500 Hz – however, this effect is not very pronounced.

The following **table** shows orientation values for string tension, string strain, and longitudinal string stiffness, for a 009-set, and for a 010-set of strings. As the vibrato lever is operated, it needs to act against the sum of all string stiffnesses plus the spring stiffnesses.

Diameter	**9**	**11**	**16**	**24**	**32**	**42**	mil
Tension force	59	50	66	75	75	72	N
Strain	4.8	2.7	1.7	3.8	2.4	1.6	mm
Stiffness	12.3	18.5	39	20	31	45	N/mm

Diameter	**12**	**16**	**24**	**32**	**42**	**53**	mil
Tension force	105	105	133	133	130	116	N
Strain	4.8	2.7	1.7	3.8	2.4	1.6	mm
Stiffness	22	39	78	35	54	73	N/mm

Table: String diameter, string tension force, string strain, and longitudinal stiffness of string.

