Quantitative Seismocardiography System With Separate QRS Detection

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Abstract. The Quantitative seismocardiography (Q-SCG) opens a new field of cardiovascular dynamics examination. Using this absolutely non-invasive method, a new field of monitoring heart rate variability was opened up. Systolic forces as well as heart rate variability in relation to changes in external stimuli are registered. Q-SCG probably offers a more complex view of both isotropic and chronotropic heart functions. It will be suitable for: examining operators exposed to stress; for assessing the effect of work, fatigue and mental stress; for monitoring persons as part of disease prevention. A new electronic system for acquisition of data for noninvasive Q-SCG and signal processing was developed. For better Q-SCG signal evaluation, also the QRS complex is detected and simultaneously registered.

1 Introduction

Quantitative seismocardiography is a noninvasive technique developed for recording and analyzing cardiac vibratory activity as a measure of cardiac contractile performance [1, 2]. This new field of monitoring heart activity, determine both amplitude-force and time-frequency relationships, is termed Quantitative Seismocardiography. [3]. Thus, one may determine the force-response of the cardiovascular system to changes in external stimuli, as well as the autonomous nervous system regulation of the circulation and the activity of the sympathetic and parasympathetic systems. The basic part of the Q-SCG is a rigid piezoelectric force transducer resting on steel chair. The examined person sits on the seat placed on the transducer and force caused by the cardiovascular activity is a measured (Figure 1). The natural frequency of the chair is higher then 1 kHz so that there is no interference with the vibrations caused by the heart activity. Neither damping nor isolation from building vibrations are necessary. These properties enabled to calibrate seismocardiographic system and determine the absolute value of force acting upon the pick-up-device [4, 5, 6, 7].

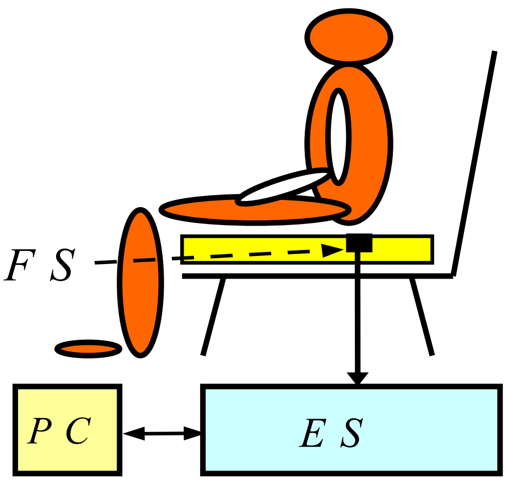

Figure 1. Principle of the convention noninvasive quantitative seismocardiography measuring: FS – Force sensor (piezoelectric transducer), ES - electronic system, PC - personal computer.

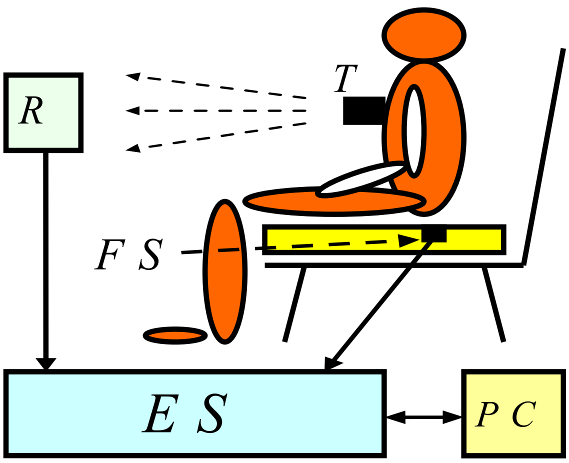

Figure 2. . Principle of the new noninvasive quantitative seismocardiography measuring:
FS – Force sensor (piezoelectric transducer), ES - electronic system, PC - personal computer,
T – device for QRS detection and transmitter (Sporttester), R – receiver.

After calibration, the Q-SCG system enables measuring heart rate (HR), systolic force (F), minute cardiac force (MF), breathing and breathing frequency (BF). It is important to note, that amplitude of measured signal from PT is sometimes under 1 mV (depend on subject heart activity) and desired frequency spectrum is lower then 30 Hz. The measured signal is corrupted by strong noise, baseline wander, movements of the patient, etc. therefore the analog and digital signal processing (DSP) must be used for signal denoising (linear analog filter and digital linear and nonlinear filters).

For better detection of important point in Q-SCG signal, the new system with separate QRS complex detection was developed (Figure 2) and devices for QRS detection with transmitter and receiver were added.

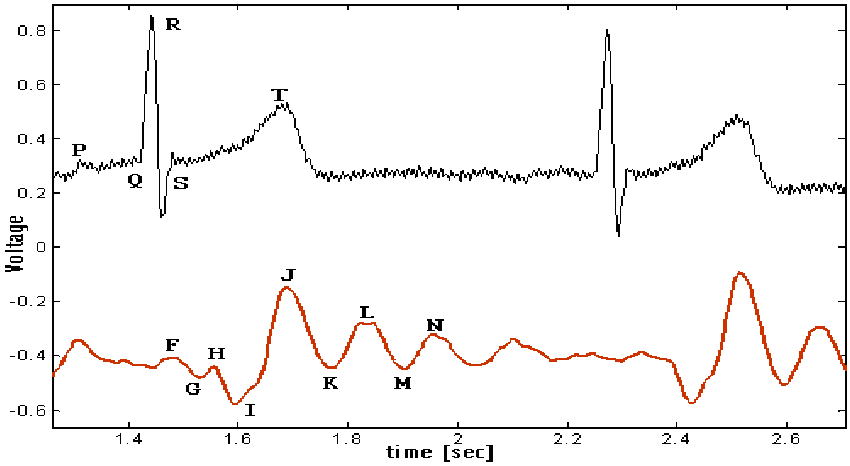

Figure 3. The important points on ECG (top) and related Q-SCG signal (bottom). Subject: Male, 14 year.

The important points in Q-SCG signal are shown in Figure 3. For comparison (and phase shift between signals), also ECG signal is presented. The Q-SCG waveform has been divided into three groups, labeled with letters: pre-injection (FGH), ejection (IJK) and diastolic part of the heart cycle (LMN).

The waveform of Q-SCG represents the different phases of the full cardiac cycle. The peek of the H-wave is localized at the end of the contraction phase of the hart and the onset of the rapid expulsion of the blood from the heart into the aorta. The I-wave point reflects the rapid acceleration of blood into the ascending aorta, pulmonary trunk and carotid arteries. The Jwave describes the acceleration of blood in the descending and abdominal aorta, and the deceleration of blood in the ascending aorta. The I-J amplitude reflects the force of contraction of the left ventricle, and the I-J interval reflects its contractility. In normal people, a repeatable pattern of waves occurs with every heartbeat.

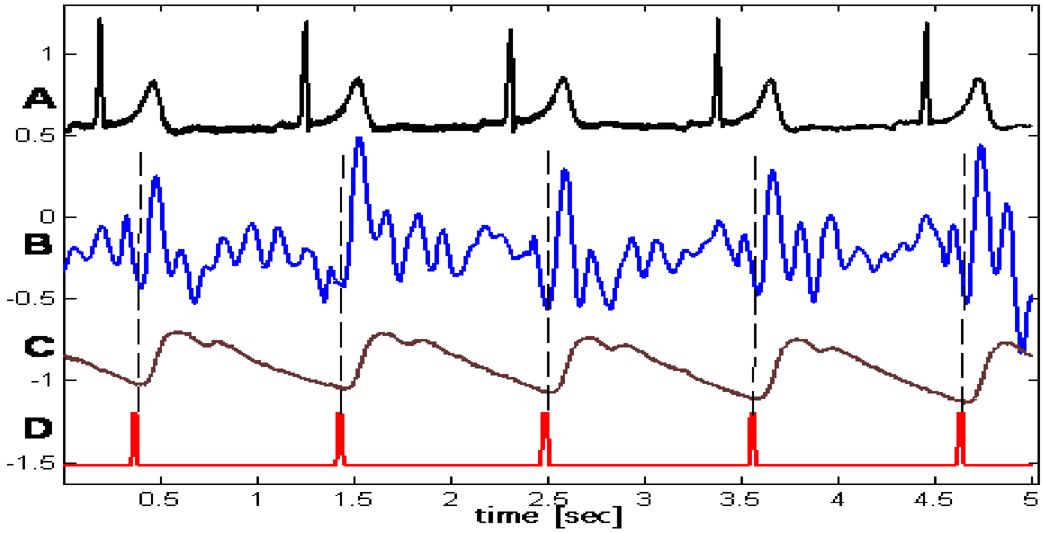

Figure 4. The time diagram of physiological signals. A) ECG signal, B) Q-SCG signal, C) blood pressure waveforms from finger, D) pulses from Sporttester. Subject: Male, 59 year.

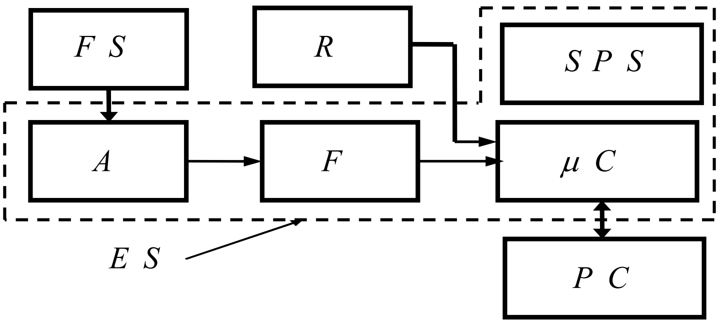

Figure 5. The block diagram of electronic system (ES). A-amplifier, F-bandpass filter, SPS-switching power supply, μC-microcontroller, FS-force sensor, R-receiver (for QRS complex), PC-personal computer.

2 New system with separate QRS detection

The principle of the new system is shown in Figure 2. The wireless device for QRS detector (with wireless transmitter) and receiver were added. The Sporttester (SPT) was used as QRS detector. When the QRS complex is detected in SPT, the narrow pulse is present on the receiver output. The time diagram of physiological signals and SPT output are shown in Figure 4.

The electronic system ES consists of amplifier (A), analog bandpass filter (F) and microcontroller (μC) with analog/digital converter and receiver (R) for SPT signal, see Figure 5. Personal computer (PC) is connected to the module via a USB cable.

For FS the DLC101-500 was used (Figure 6 and 7). The integral IC is powered by a single coaxial cable with 2 to 20 mA of constant current. The voltage produced by force acting upon the sensor is superimposed on a +11 V bias voltage at the sensor connector. The input force stresses the quartz crystal producing an electrostatic charge Q, which charges total shunt capacity C instantly to voltage V=Q/C. The MOSFET input IC amplifier operating in unity gain, source follower mode, is supplied with constant current. The +11 V DC is “removed” or blocked by capacitor.

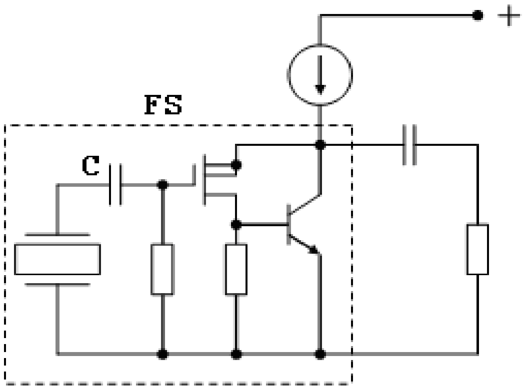

Figure 6. The force sensor DLC101-500 internal circuit.

Figure 7. Photo of the force sensor.

The analog bandpass filter (F) consists from lowpass and highpass filters. Cut-off bandpass filter can be electronically controlled. 2'nd order highpass and 8'th order lowpass switched capacitor filters were used. Frequency and phase responses are shown in Figure 8.

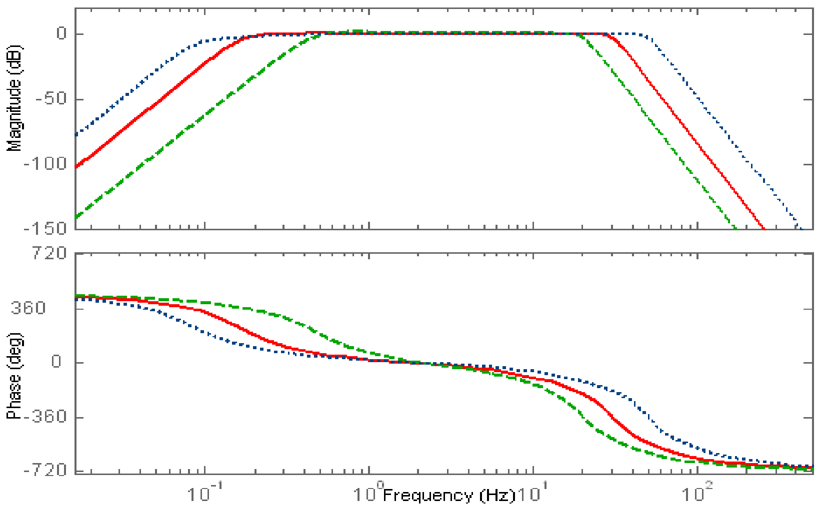

Figure. 8. The frequency and phase responses of electronically controlled analog filter.

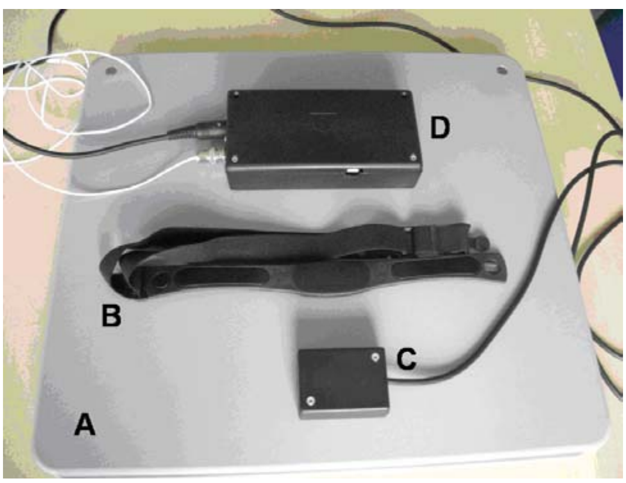

Figure 9. The seosmocardiographic system. A-plate with force sensor, B-Sporttester belt (with QRS detector and transmitter), C-receiver, D-electronic system.

Figure. 10. Rigid chair equipped with plate containing force sensor for Q-SCG measuring. Size of the plate is 45x45 cm.

In switching power supply (SPS) step-up switching IC's and inverting switching IC's were used for generating ±15 V from single +5 V supply.

3 Results

The system for Q-SCG measuring was built according block diagram (Figure 5). The sampling rate was set at 960 samples/second, which is sufficiently oversampled to enable decimation, digital filtration, etc. The PC contains special software that controls the module's functions and receives of digitized data. Data are stored on hard disc and also displayed and processed.

All parts of the system are shown in Figure 9, rigid chair with plate in Figure 10. Waveform during the examination (on line) is shown in Figure 11, Q-SCG signal (top), SPT pulses (bottom). Moreover, in the window, heart rate, file number, speed and elapsed time are shown and control buttons for Stop and Continue are also inserted.

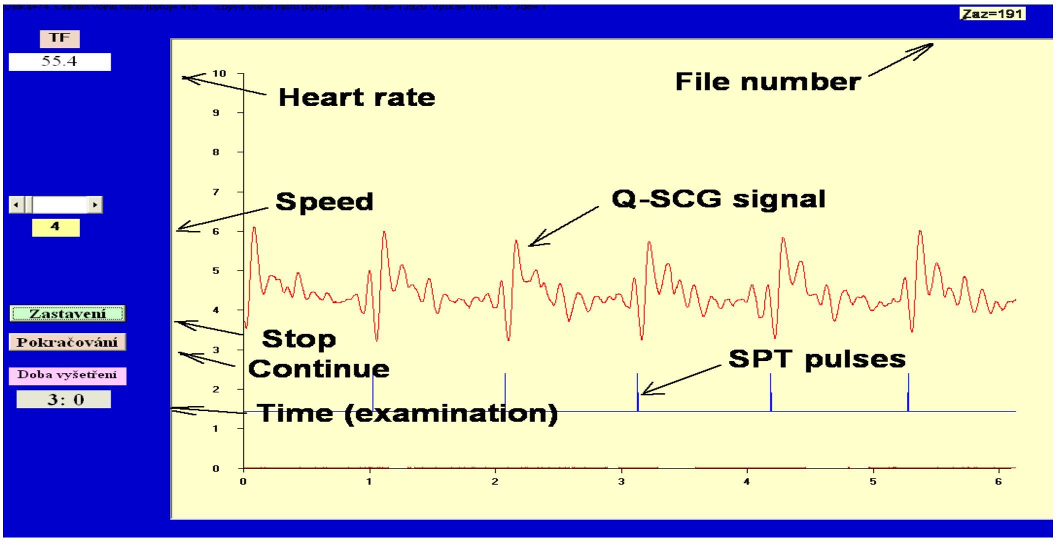

Figure 11. Window during the examination. Q-SCG signal (top), SPT pulses (bottom). Labels with heart rate value, file number, speed and elapsed time are shown and control buttons for Stop and Continue are also inserted. Subject: Male, 59 year.

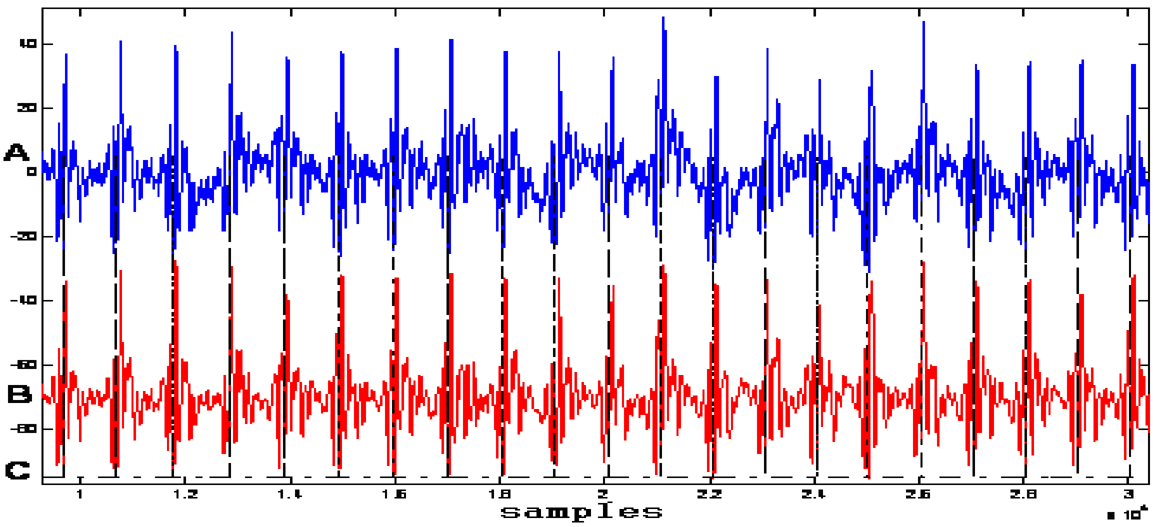

Figure 12. Example of measured and processed signal. The Q-SCG raw signal (top), filtered signal (bottom) and SPT pulses (bottom - dash). Subject: Male, 59 year.

During the examination, the sampled signals are stored in file and can be used for off-line digital signal processing. The most significant drawback of the Q-SCG is its high sensitivity to movements of the patient. To gain important point and information from the signal that would correctly describe the state of the patient, it is necessary to keep stable measurement conditions and especially to keep the patient in a motionless position during the examination. Typically, the examination takes about five minutes. It is obvious that for such a long period it is very hard for the patient to keep motionless. The linear and nonlinear methods were used for digital signal filtering [8, 9, 10]. The main advantage of new system (with separate QRS detection) is exact detection of important points in Q-SCG signal. Example of raw sampled signal measured by new system is shown in Figures 12 and 13. The raw signal (filtered only analog filter), filtered signal and SPT signal are shown in Figure 12 and zoom in Figure 13. The important points of filtered Q-SCG signal are shown in Figure 14. It can be seen (bottom signal, Figure 12 and 13 and 14) that baseline wander of the Q-SCG signal was improved and noise was removed. It is important to notice, that Y-axes in Figures 12, 13 and 14 are not in scale (but signal in Figure 11 - time and force are in scale).

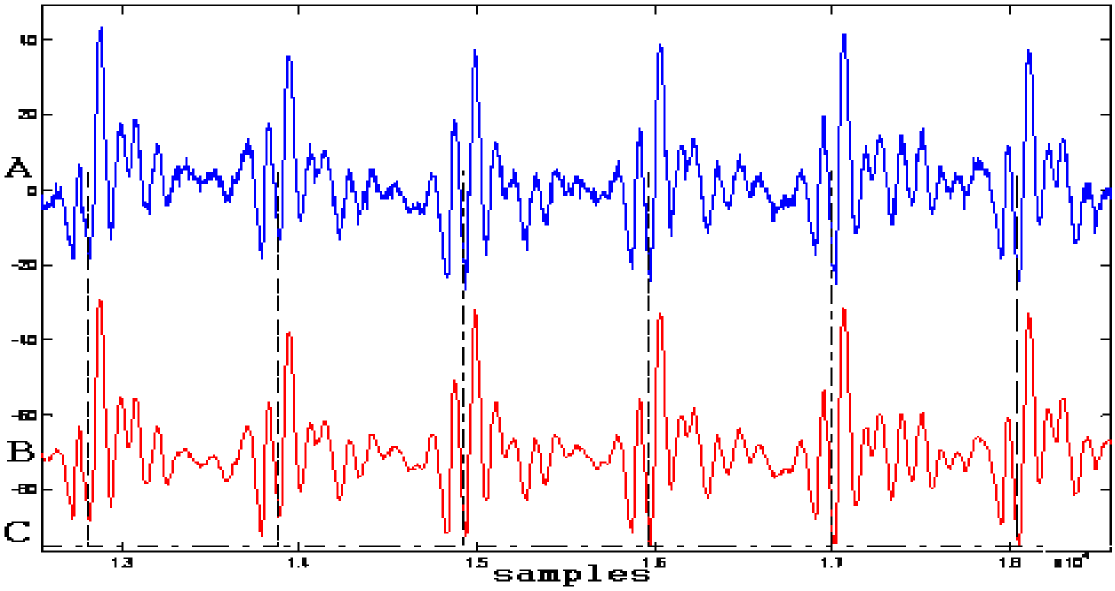

Figure 13. The zoom of Q-SCG raw signal (top), filtered signal (bottom) and SPT pulses (bottom - dash). Subject: Male, 59 year.

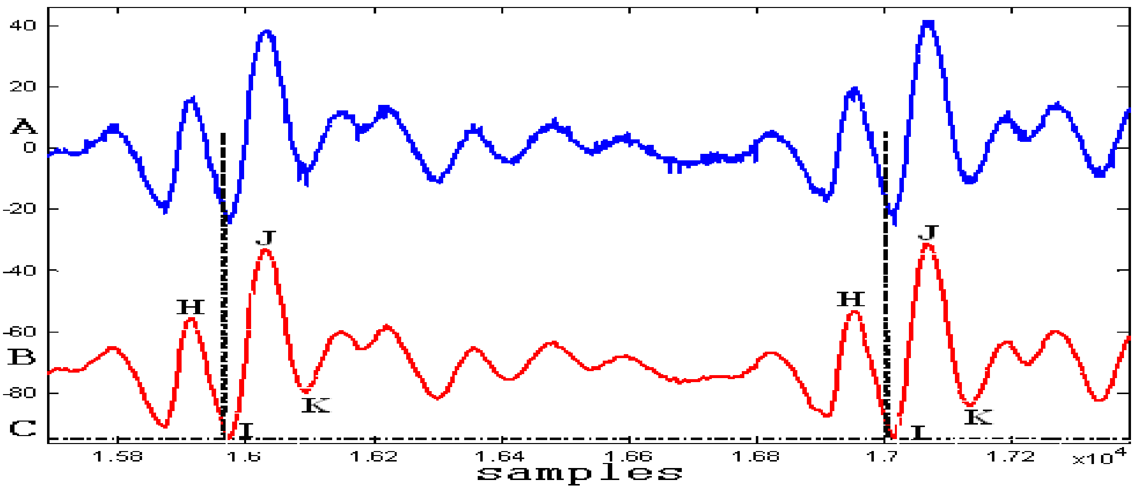

Figure 14. The Q-SCG signal with noise (top), important points of filtered Q-SCG signal (bottom) and SPS pulses (dash). Subject: Male, 59 year.

The heart rate variability (HRV) can be also evaluated from Q-SCG signal. The signal processing example for beat to beat detection is shown in short time slice of signal in Figure 14 (bottom). After calibration (Y axis in Newton), the systolic force *F* and minute cardiac force *MF* can be computed according (1) and (2):

$$F = (F_{HI} + F_{IJ} + F_{JK})/3 \qquad [N] \qquad (1)$$

$$MF = F * HR \qquad [N, beats/min] \qquad (2)$$

where *HR* is heart rate and F_{HI} , F_{IJ} , F_{JK} can be find according Figure 14. The systolic force *F* represent the force response caused by the heart activity and is expressed in units of force [Newton]. For the total intensity of the heart activity is introduced the minute cardiac force *MF* which equals the systolic force multiplied by the *HR*.

4 Discussion

The anatomy and function of single organs of human organism are in correlation. This is true for muscle mass, the body weight and the muscle force too. The reason of this fact is that higher body weight needs for the defined movement greater force, which cannot be realized but by the development of the skeletal musculature. Consequently greater musculature needs more energy which is transported and distributed by the cardiovascular system. In addition, the increased performance of the cardiovascular must be adjusted by the heart muscle. From these relationship it can be concluded that there must be not only the correlation between the skeletal muscle force and the heart mass but also between the skeletal muscle force and the systolic cardiac force as it was observed in the present study. The described, new quantitative seismocardiographic system expanded and improved functions of an earlier version of the system. The separate QRS detection system offers more complete evaluation of quantitative seismocardiography.

Some differences in Q-SCG waveforms between different people can be explained by the state of their cardiovascular system. It can be shown that arterial elasticity is lower with hypertensive persons. Also, the level of physical fitness and the age of person have their own influence on the measured signals.

5 Conclusions

The new principle of Q-SCG, measuring system for noninvasive measuring of heart activity and heart rate variability was presented. The measuring system also use circuit for QRS complex detection. The QRS pulses are wireless transmitted and simultaneously registered by receiver.

The separate QRS detection system enable better detection of important points in measured signal. The system was constructed and tested. The basic part of signal processing for Q-SCG was also developed and results were described, but the new software for continuous systolic force evaluating, cardiac force measuring and heart rate variability estimation is in development.

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