10 Combustion and Flame Fronts

In Chapter 5 on Pistons and Cylinders we looked briefly at several topics related to power production, namely compression ratios, squish and detonation. Later we looked at carburation and inlet tract design.

What I propose to do now is to discuss the quality of power production from the view point of charge preparation, the charge manipulation and charge ignition (“How do I make it?” and “Where do I put it?”). The fuels that I will consider are petrol and methanol, and I propose to start with the combustion process itself and consider how that might be best assisted

The combustion process is initiated by the spark at the plug. If that is not so, then we are already in deep trouble, but that is another story. The spark timing varies according to engine, exhaust and state of tune. In general, the poorer the engine is in terms of design and tune, the more advance you need. A typical value for Vintage Racing eligible engines in good tune would be 20°BTDC, lesser motors might be 23° or 25°. All the air-cooled RD Yamahas used 20°BTDC, and the full race TZ’s used 16°BTDC.

A good spark at the electrodes might last 20 microseconds and generate local temperatures of 60,000°C. This is easily enough to lift the fuel vapour between the electrodes above its flash point of 220°C and a kernel of ignited vapour about 1mm across is created. Within 1 millisecond the kernel has expended to 5mm in diameter and is losing heat rapidly, and thereafter burns its way across the combustion chamber in a controlled fashion. The problem is that it is too controlled, too slow in fact.

The flame front, or the ‘combustion zone’ if you prefer, is a self-sustaining exothermic chemical reaction about 1mm wide that will consume unburned fuel until the fuel is exhausted, or the combustion zone energy can no longer raise the adjacent fuel above its flash point. This self-sustaining flame front burns lazily at about 0.35m/sec in petrol and about 0.45m/sec in methanol, this is too slow for our needs. It needs some encouragement! Give it some grief (ie: turbulence, difficult not to do since it the fuel has just come up the transfer port) and you might get 5 to 10 m/sec turbulent burning. If only we could impart some real speed into the swirling mixture then we would be better off.

Enter the ‘squish head’. The squish head serves two purposes, the first is to create a jet of high speed gas at TDC and the second is to create a combustion end zone buffer where the almost nil clearance between head and piston will indeed remove heat from the combustion zone faster than it can be generated and so quench the flame. Controlling the squish clearance is vital and tiny changes in squish clearance can make large differences in jet speed. Too much clearance gives poor jet speed and too little clearance combined with an underestimate of crankshaft flex or conrod stretch will lead to piston and head physical contact at high RPM. The combustion zone now rides the jet wave and combustion is complete in a fraction of the time. The jet speeds are in the order of 10 m/s for 40 thou squish and 25 m/s for 20 thou squish. The squish effectively forces the engine to approach the ideal condition of burning at constant volume. Ideal for modelling that is, ideal in the sense of the perfect Otto cycle. There is always a price to be paid: more pressure more stress more vibration. Higher velocities means more heat transferred to head and cylinder walls, reducing the risk of detonation. The squish presents a relatively large area for its volume and is therefore able to douse the flame at the margins.

If the process in the flame front becomes ‘overheated’ or too much heat generally is added to the unburned fuel, then the unburned fuel reaches its spontaneous combustion temperature before the arrival of the flame front, then the whole of the unburned charge in the area will auto-ignite giving rise to huge temperatures and pressures. The pressure will give a ‘knocking’ sound and the temperatures may melt your piston.

The process of spark plus flame front will have taken not less than 30^{o} of crank, thus to an approximation we have released all of the heat into the combustion chamber more or less at constant volume. It is the release of this heat that will give us the pressure that we need to do useful work. This pressure forces the piston downwards until the exhaust port opens, which in our typical engine will be about 90^{o}ATDC. The piston will have maximum velocity then the crank/bigend/smallend are at right-angles, and this occurs at about 72^{o} ATDC, so the piston is decelerating quite noticeably by the time that the exhaust port opens. Typical values are 8 bar pressure and 1500^{o}C at exhaust port open down from a maximum of 50 bars and 2500^{o}C. Work at QUB (Gordon Blair *et al*) and MIT (John Heywood *et al*) .has shown that in a typical tuned 2-stroke we might see

	Pressure Bar	Temperature Degrees C	
Scavenge	1.2	250	
Ignition	10	450	
Burning	50	2500	at about 10^{o} ATDC
Exhaust Open	8	1500	

some other typical temperatures are

Piston top	250
Piston skirt	160
Small end	120 - 150
Big end	100 - 150

In considering the combustion process it is tempting to think that all, or almost all, of the burnt gas has been expelled by the swirl of the new charge