

Motorcycle Handling and Chassis Design

the art and science

Tony Foale

Foreword

The motorcycle is a complex system that has long defied full analysis. For a very long time, motorcycle handling was hardly even considered a subject. Engines, whose performance could be measured in "objective" terms, therefore received the lion's share of development. Engine development moved rapidly ahead of chassis, suspension, and tires, creating a succession of design crises that required new thought for their solution. Examples might be Rex McCandless's twin-loop swingarm chassis of 1950, Tony Mills's wide, belted Dunlop Daytona tire of 1974, and the present-day elaborations of Antonio Cobas's large-section aluminium twin-beam chassis of the early 1980s. In each case, motorcycle performance had ceased to advance because of specific problems that could not be solved by traditional means.

In general, the innovations that have broken these deadlocks have been creations of practical persons, not of theorists. The role of theory in motorcycle design has, if anything, suffered at the hands of history, for the strange forkless creations of ELF, Fior, and Bimota have come and gone without solving any actual problem.

Yet motorcycle performance is at present again deadlocked, with no sunny uplands of easy progress in sight. As motorcycles lean over farther on their wonderful tires, their suspensions turn sideways, at a large angle to the bumps they are designed to absorb. As engine and brake torque is applied, motorcycles short enough to turn quickly, and tall enough for adequate cornering clearance suddenly lift the front or rear wheel, limiting maximum rates of acceleration and deceleration. While autos present 100% of the width of their tires to the pavement, the motorcycle offers only 1/3 of tread width at a time, severely limiting cornering grip. To make motorcycles steer well, front tires must be of modest section, while rears, to apply engine power, must be large. With the forward CG position necessary for rapid acceleration, a powerful motorcycle must therefore overload its small front tire in cornering, while under-using its larger rear. The result is that as a machine's power increases, its corner speed must decrease.

Racing is the environment in which these problems hurt worst, and from which solutions have most often come. Racing has, however, evolved from a sport into a conservative business. The practical men of racing are now too busy loading and unloading their beautifully painted transport trucks to have much time for innovation. The theoreticians remain, as ever, divorced from practicality, often ignorant of the real problems motorcycles confront.

Yet the infinite refinement of the piston internal combustion engine did not create the gas turbine - only a careful consideration of theoretical heat engine cycles could make that leap. Therefore the practical and theoretical sides need each other - but they have had little dialogue thus far.

This book is a valuable step toward that dialog. Tony Foale's first book was almost entirely practical, and has been deservedly widely read. He is a man who can control a weld puddle and twist safety wire. He also knows that refinement within existing thought must ultimately reach a dead end. This has forced him to learn to walk with one foot upon practicalities and the other upon theory. This new book is the result. Read on.

Kevin Cameron. Technical editor Cycle World magazine. March 2002.

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Preface

The book "Motorcycle Chassis Design" was first published in 1984 and was subsequently reprinted several times without under-going change. Although out of print for over 12 years or so, I know from personal inquiries that there is still considerable demand for a book on this subject. A new book was obviously well overdue, although much of the original material is as current today as it always has been. After all, the laws of Newtonian Physics tend to be stable over time.

During the nearly two decades since the original book, the motorcycle chassis has undergone gradual evolutionary change and there is no doubt that handling in general has improved. In the 1970s. the main emphasis was on ever more powerful engines being fitted into flexible tubular frames unable to provide a reasonable level of handling or stability. Thankfully that has generally changed. Forks, frames and swing-arms have become much more rigid, and in some cases lighter as well, at least at the sport bike end of the market. The change to radial ply tyres has been of the utmost importance to this process of change. Despite the prophecies of many commentators the front suspension of choice is still the telescopic fork, although generally much improved. For any number of reasons manufacturers have been reluctant to experiment with other forms in the marketplace. This probably has more to do with the product liability lawyers than it has to do with the engineers. There have been two notable exceptions amongst the major manufacturers. Although now out of production, Yamaha marketed the GTS with a suspension design based on the work of James Parker. BMW changed over completely to the "Telelever" system, similar in principle to the design used by the British Saxon concern.

I've had considerable feedback from readers of that first book and I've done my best to incorporate the many suggestions. Although greatly enlarged, most of the original subject matter remains. Many topics have under gone revision to improve clarity or remove ambiguity. Material has been added which explores in more depth those subjects which were only briefly mentioned in the original book, mostly due to publishing space constraints. An example of this is the description of initiating a turn, this topic is central to an understanding of motorcycle behaviour. However, it was then covered only briefly, the content on this subject is considerably enhanced in the current book. Completely new chapters have been added on various topics that just weren't in the original. For example: tyres, aerodynamics, the important subject of anti-squat and a case study of improving a standard production frame for racing.

Since the first book was published the sport of motorcycling in all forms has become much more technical and so in order to do the subject justice this book has had to become more technical also. Reviewers of the previous book praised the lack of drawn out explanations, I have tried to maintain this characteristic where possible, but within the need for coverage in greater depth. This book is not intended as a handbook for chassis setup etc. rather it is an attempt to provide the reader with the background knowledge of how and why motorcycles react in the way that they do. An understanding at this level will however, equip the reader to undertake his own design, modifications or setup with greater confidence. The acquisition of knowledge is rarely easy and requires commitment, any book is purely a passive aid and the benefit to each reader will depend on the effort put into it. It is probably best to initially read it through quickly, ignoring some of the detail to get an overall view and then to re-read it to gain a more in-depth appreciation of the subject. It is also recommended that the reader looks at some of the appendices for background information, prior to tackling the main text. In particular appendices 2,3 and 4.

There are a wide range of technical topics discussed within a relatively small book and so in some cases a prior knowledge of the basics has had to be taken for granted. Naturally some parts of the general text are more technical than others, but there should be little problem for any interested enthusiast in gaining a better understanding of the principles involved. It is not necessary to understand every last detail to derive benefit.

To cover the subject adequately it is impossible to completely avoid mathematics, I have tried to keep this as simple as possible. The level of mathematics used is deliberately kept at a level below that requiring a knowledge of calculus, in the hope that the book will be of use to the widest range of readers. A multitude of diagrams and graphs from both data logging and computer simulation have been used to demonstrate various phenomenon without a great number of formulae.

Even in this age of much greater technical understanding, there are still many aspects of design and handling setup that can better be described as art more than science. Hence, the book title has been changed to reflect this. All engineering design is the art of compromise, the best bike is the one whose designer has achieved the best overall compromise for the intended purpose, whether that be racing or commuting. We often hear that competition machines are built with no compromises, in fact the opposite is true. Highly focused machines such as racers are probably subject to the biggest compromises of all. Throughout the book I have tried to emphasize the conflicting requirements that always compromise any design or setup decision. Nowhere is this more evident than when selecting suspension characteristics, this is demonstrated at every race meeting where much time is spent making minute adjustments to achieve the "optimum" setup.

Many points in the text are illustrated with example photographs. It has been a policy to use older examples where possible to acquaint younger readers with some of these machines and also to demonstrate that much of what is regarded as being new has in fact been around for a considerable period. Most readers will in any case be familiar with photos of modern examples from the general motorcycle press.

The first book was co-authored by Vic Willoughby, undeniably the doyen of motorcycle technical journalists. When I was a teenager (many years ago) I would read his weekly articles many times over and there's no doubt that these played a great part in the motivation for me to start designing and making my own chassis. Many years later I was privileged enough for him to write articles describing some of my work. We became friends and I was honoured when he agreed to help when I approached him with the idea for the original book. He was in his retirement then but still had enormous energy for the task. Unfortunately, Vic passed away in November 2000 and I have undertaken this new book solo, and so must take sole responsibility for any errors.

I would however, like to dedicate this book to Vic. without whom the original would never have passed the idea stage.

Tony Foale, Spain

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