from the deformations of the shaft or of the cutting disk support, the cutting head or the shaft of the cutting head, when measuring the different boring parameters.

Regardless of the proposed methods, the pilot must systematically deduce, from the values measured by the different sensors, the conditions imposed by the ground being penetrated and adjust different characteristics of the tunnel boring machine (speed of advance, torque, etc.) as a function of these values. This adjustment must, however, take into account the type of tunnel boring machine used, and therefore requires considerable expertise on the part of the pilot. Moreover, the nature of the ground is not generally homogeneous, so that the values obtains may not be representative of the true nature of the ground at the tunnel face.

SUMMARY

One object of the present disclosure is therefore to propose a method for optimizing the characteristics of a tunnel boring machines, in particular a slurry pressure or variable density type tunnel boring machine, which allows optimizing in real time the characteristics of the tunnel boring machine so as to improve boring without risking damaging the tunnel boring machine, regardless of the nature of the ground at the tunnel face or even the type of tunnel boring machine used.

In an aspect, the present disclosure refers to a method comprising the following steps:

obtaining from a database a set of boring parameters characterizing formation of a bore by at least one given tunnel boring machine over at least one boring site, the set of boring parameters including at least one of a torque of a cutting wheel of the at least one given tunnel boring machine, a speed of rotation of the cutting wheel of the at least one given tunnel boring machine, a speed of advance of the at least one given tunnel boring machine, a contact force of the at least one given tunnel boring machine, a surface area of the cutting wheel of the at least one given tunnel boring machine, a radius of the cutting wheel of the at least one given tunnel boring machine, and a confinement pressure at an axis of the at least one given tunnel boring machine,

identifying a set of energy formulas depending on at least one of the boring parameters,

determining a set of variables based on the energy formulas thus identified, the set of variables including at least one of an average, maximum, and standard deviation of the energy formulas,

applying a non-supervised classification algorithm to the variables so as to obtain groups of individuals identified according to a predefined criterion of the non-supervised classification algorithm,

applying a supervised classification algorithm to the variables and to the groups of individuals thus determined so as to obtain a ground/machine interaction model connecting the variables to the groups of individuals,

measuring, while boring a ground with a tunnel boring machine, at least one boring parameter, the at least one boring parameter comprising a torque of a cutting wheel of the tunnel boring machine, a speed of rotation of a cutting wheel of the tunnel boring machine, a speed of advance of the tunnel boring machine, and a contact force of the tunnel boring machine,

determining the group of individuals corresponding to the measured at least one boring parameter using the ground/machine interaction model, and

modifying at least one of the boring parameters of the tunnel boring machine as a function of the group of individuals thus determined.

In an aspect, the present disclosure refers to a system comprising:

a database storing a set of boring parameters characterizing formation of a bore by at least one given tunnel boring machine over at least one boring site and storing a ground/machine interaction model determined by:

identifying a set of energy formulas depending on at least one of the set of boring parameters, the at least one boring parameter including a torque of a cutting wheel of the at least one given tunnel boring machine, a speed of rotation of the cutting wheel of the at least one given tunnel boring machine, a speed of advance of the at least one given tunnel boring machine, a contact force of the at least one given tunnel boring machine, a surface area of the cutting wheel of the at least one given tunnel boring machine, a radius of the cutting wheel of the at least one given tunnel boring machine, and a confinement pressure at an axis of the at least one given tunnel boring machine,

determining a set of variables based on the energy formulas thus identified, the set of variables including an average, maximum, and/or standard deviation of the energy formulas,

applying a non-supervised classification algorithm to the variables so as to obtain groups of individuals identified according to a predefined criterion of the non-supervised classification algorithm, and

applying a supervised classification algorithm to the variables and to the groups of individuals thus determined so as to obtain a ground/machine interaction model connecting the variables to the groups of individuals; and

a processor configured to:

measure, while boring a ground with a tunnel boring machine, at least one boring parameter, the at least one boring parameter comprising a torque of a cutting wheel of the tunnel boring machine, a speed of rotation of a cutting wheel of the tunnel boring machine, a speed of advance of the tunnel boring machine, and a contact force of the tunnel boring machine,

determine the group of individuals corresponding to the measured at least one boring parameter using the ground/machine interaction model, and

modify at least one of the boring parameters of the tunnel boring machine as a function of the group of individuals thus determined.

To this end, in a first example, the present disclosure proposes a method for determining a ground/machine interaction model during boring of a ground by a tunnel boring machine, in particular a tunnel boring machine of the slurry pressure or VD (Variable Density) type, said method comprising the following steps:

- S1: obtaining, by a processing unit, a set of boring parameters characterizing a bore by at least one given tunnel boring machine over at least one boring site, particularly a tunnel boring machine of the slurry pressure or VD type, said set comprising parameters obtained by sensors;
- S2: identifying, by the processing unit, a set of formulas depending on all or part of the boring parameters,

According to a second example, the present disclosure also proposes a method for optimizing the characteristics of a tunnel boring machine, particularly a tunnel boring machine of the slurry pressure or VD type, said method comprising the following steps:

- S0: determining, by the processing unit, a ground/machine interaction model according to the first aspect,
- S11: instantaneous measurement, by the processing unit, of the set of specific boring parameters of the tunnel boring machine,
- S13: determining, by the processing unit, the group of individuals corresponding to the boring parameters measured in step S11 by means of the ground/machine interaction model,
- S14: modifying, by the processing unit, the characteristics of the tunnel boring machine as a function of the group of individuals thus determined.

Certain preferred but non–limiting features of the optimization method above are the following, taken individually or in combination:

- the optimization method also comprises, prior to step S13, a step consisting of calculating all or a part of the variables determined in step S3 based on the boring parameters measured in step S11, and wherein, during step S13, the group of individuals is determined by applying the ground/machine interaction model and to the variables thus determined and/or
- during boring, the tunnel boring machine successively deposits a plurality of rings, and the steps S11 to S14 are repeated during the deposit of each ring.

According to a third example, the present disclosure also proposes a computer program product comprising code instructions for executing a method for determining a ground/machine interaction model during boring of a ground by a tunnel boring machine, particularly a tunnel boring machine of the slurry pressure or VD type as described above and/or a method for

optimizing the characteristics of a tunnel boring machine, particularly a tunnel boring machine of the slurry pressure or VD type as described above.

According to a fourth example, the present disclosure proposes a storage means readable by data processing equipment on which a computer program product comprises code instructions for the execution of a method for determining a ground/machine interaction model during boring of a ground by a tunnel boring machine, particularly a tunnel boring machine of the slurry pressure or VD type as described above.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features, aims and advantages of the present invention will appear more clearly upon reading the detailed description that follows and with reference to the appended drawings given by way of non–limiting examples and in which:

Figure 1 is a partial section view of an embodiment of a tunnel boring machine conforming to one embodiment of the invention.

Figure 2 illustrates schematically an exemplary embodiment of a processing unit adapted to execute the optimization method according to the invention, as well as the input parameters of said processing unit.

Figure 3 is a flowchart illustrating the steps of an exemplary embodiment of an optimization method conforming to the invention.

DETAILED DESCRIPTION OF AN EMBODIMENT

In order to optimize parameters for a tunnel boring machine 1, in particular a tunnel machine 1 of the slurry pressure or variable density (VD) type, during boring, the invention proposes to first determine a ground/machine interaction model (method S0). The optimization of the characteristics of the tunnel boring machine 1 is then accomplished based on this ground/machine interaction model (optimization method S10), and no longer solely based on the theoretical ground at the tunnel face. In fact the method S10 starts with the principle according to which grounds of